New trends in physics teaching

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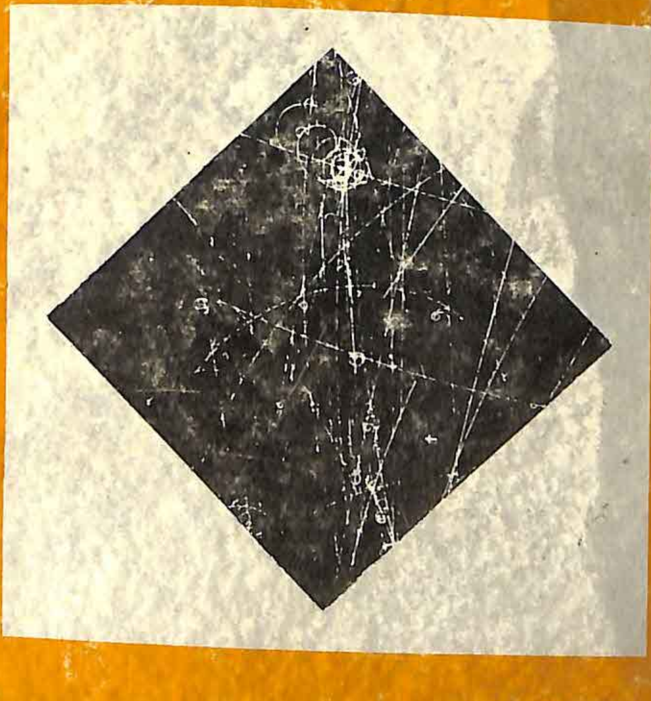

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New trends in physics teaching

Volume III

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Based on the proceedings of the
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Preface

The worldwide exchange of ideas and information plays an important role within Unesco's programme to promote innovations for the improvement of science education at all levels. One of Unesco's contributions to this international exchange is the publication of a series on *The Teaching of Basic Sciences.* Volumes entitled *New trends in the Teaching of . . . . . .* have been published within this series, each of them covering one of the five subjects mathematics, physics, chemistry, biology and integrated science. So far two, three or four volumes have appeared in each of these since the series started ten years ago. Additionally, a volume was published under the title *New Trends in the Utilization of Educational Technology for Science Education.*

New Trends in Integrated Science Teaching, volume 3 and *New Trends in Chemistry Teaching, volume 4* were the outcome of two major international conferences held in 1973 (in Maryland, USA and in Wroclaw, Poland respectively). It was decided to adopt the same procedure for the next volumes in biology, physics and mathematics. For the physics meeting Unesco worked with the International Commission on Physics Education (ICPE) of the International Union of Pure and Applied Physics (IUPAP). This was a natural choice in view of the already well-established pattern of collaboration between ICPE and Unesco and the successful completion of several joint projects. Preliminary discussions between Unesco and ICPE, initiated in 1973, were followed by the setting up of an international planning committee, a national committee and a local organizing committee. Close collaboration between all these bodies led in due course to the International Conference on Physics Education (Edinburgh, 29 July to 6 August 1975). The Conference was convened by IUPAP, through ICPE, and was sponsored and supported by Unesco, The Royal Society, the Institute of Physics and the University of Edinburgh. Further financial support was provided by the British Council and a number of official and private organizations in the United Kingdom.

The present volume is the result of the discussions that took place in the working groups at the above-mentioned international conference. Each of its twenty chapters covers one specific aspect of the overall field of physics education. Some chapters refer to university education, some to secondary school education and some to problems related to both levels. Some chapters also deal with non-formal education.

This book is addressed to all those who are actively interested in the improvement of physics education at whatever level – teachers in universities and teacher-training institutions, officials at ministries of education, members of examination boards and of teachers' associations, secondary-school teachers, school inspectors, curriculum supervisors, students preparing to become physics teachers, etc. Certain chapters could also be of use as background material at national or regional seminars devoted to specific aspects of the process of improving physics education in the context of a national educational system or in the light of the problems common to a group of countries. The purpose of this book is to facilitate access to an international pool of ideas and information on various approaches to the improvement of physics education; each reader will analyse them and decide which approaches may be adequate and useful to the conditions in which he or she is working.

Unesco wishes to express its appreciation to all the many persons who helped, directly and indirectly, in the preparation of this book. Special thanks are due to the editor of the volume, Mr. John L. Lewis, and his two co-editors, Mr. Jim Jardine and Professor G. Delacote, for the competence, the care and the patience with which they carried out their difficult task.

Editorial foreword

This book is an outcome of the International Conference on Physics Education which was held at the University of Edinburgh from 29 July to 6 August 1975.

Each of the 20 chapters of this volume is based on the discussions that took place in the working groups, which constituted the main activity of the Conference. The topics of discussion covered very broadly the whole field of physics education at both university and secondary levels. Although each working group had a 'trend paper' which had been prepared and circulated in advance of the Conference as a basis for its discussions, each chapter in this book is the result of the collective efforts of the members of the corresponding working group. A great debt is owed to the authors of the working papers, not only for having written them in the first place and having thus set a fruitful framework for the discussions at the Conference, but also for their help and understanding during the Conference and in the subsequent editorial stage. Likewise, I am grateful to those who chaired the discussions as well as to the secretaries of the working groups and to all those participants who contributed to the discussions.

I would like also to express my indebtedness to the staff of Unesco for their help and encouragement. Finally, I wish to place on record my gratitude to the co-editors of this volume, Jim Jardine and Professor Goery Delacote, who have always been willing to help ungrudgingly whenever called upon to do so.

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Education

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1 The post-graduate education of physicists

The original paper used as the basis for discussion at the Edinburgh Conference was written by M. Cernohorsky and an edited version forms the first part of this chapter. Unfortunately Professor Cernohorsky was not able to attend the conference and the second part of the chapter, written in his absence, is the outcome of discussion at that conference.

1.1 INTRODUCTION

The international nature of physics education is in no way comparable with the international nature of physics itself. The internationally understandable language of physics and the international structure of physical science have no counterparts in the national or regional features of physics education. This is one reason underlying the need for world-wide cooperation in physics education.

Even the words 'post-graduate education' have different meanings in different national educational systems. In this chapter the term will be used to mean any further education of a person already holding a first university degree in physics or its equivalent. We will focus on new developments and needs in training physicists:

(a) to serve mainly as staff members in university physics departments, with primary emphasis on research but including preparation for their teaching activities;

(b) to serve mainly as staff members in tertiary-level institutions with physics teaching as their major activity;

(c) to serve as research workers and to occupy other positions in industry and in other professions and disciplines.

1.2 SCIENCE, INDUSTRY, EDUCATION – THE MAIN PROFESSIONAL AREAS

It is not possible to describe here the situation in all countries, nor to point out all the specific problems concerning different economies, different cultures, different industries and research situations. Findings relevant to one country may not be applicable to another. Nevertheless, it is worth while quoting certain characteristic standpoints adopted over the last fifteen years which have led to new developments. In choosing these we have preferred those relevant to the present situation without regard to the chronology.

The main line of university education in physics deals with the full-time studies of young people between the ages of 18 and 27 who are preparing for careers in physics, physics teaching or one of other professions requiring a knowledge of physics [5, p139].

All university programmes essentially comprise two stages. The first stage, primarily of a tutorial nature and lasting three to six years, is followed by another which usually lasts two to five years. The two stages are not necessarily separate and may in some cases overlap. Some physicists terminate their university education at the end of the first stage [11, p25].

Comparatively few students have an opportunity to carry out research at the frontiers of knowledge. Such research normally requires about two years of advanced study and research (leading to an intermediate degree) followed by three to seven years (for the doctoral degree). Although the emphasis in post-graduate education lies on research, several countries have found it useful to add to their programmes advanced courses in physics as a means of raising the competence of the student to the highest possible level and of imparting to him the latest knowledge in the field [5, p127].

However, the following quotation [10] from B.H. Flowers suggests that university science education in general, not only in physics, tends to be narrow:

> "University education culminating in a Ph.D. is at its best an admirable preparation for scientific research and teaching, but in many fields it seems to be out of touch with the wider problems of science and technology outside the research laboratory. Without doing harm in any way to the Ph.D. at its best or to the proper needs of scientific research, we therefore wish to see the spectrum of possibilities for postgraduate studies broadened by the inclusion in some cases of work which is not traditionally regarded as scientific research . . . . The traditional Ph.D. as a training for research must show a student how to penetrate in depth at a particular point in his subject albeit within a wider context. But to deal with many problems in industry or administration, what is needed is a capacity to grasp essential facts and ideas over a very wide area, and by seeing in depth the interrelations between them to plan the right action . . . . the chief initiative must still come from industry, for industry has more to gain directly from it than the universities."

C.G. Suits previously said in 1960 [6]: "If we, in industrial research, had a choice between abbreviated formal course work and full research training, on the one hand and full formal course work and a resultant shorter period of research training, on the other hand, I think we would choose the latter." And he put a question concerning the length of the post-graduate education: "What may happen in the distant, but not too distant future, is interesting to contemplate. Will graduate training in physics then require 6 or 7 years, rather than the present 4 or 5 and former 2 or 3? It is a question of what we will omit from the future course of study, for I would view with considerable alarm any further encroachment on the period of productive effort of the research physicist."

The same approach was widely shared at international level eight years later in 1968 [11, p27]:

> "Industry prefers to employ men at the earliest possible age and the second stage is recommended to last 3 years at most. Students may well complete a first-stage physics course followed by some other post-graduate course, e.g. business studies, engineering or other science. Such persons will readily obtain industrial employment."

This last idea is increasingly gaining ground. A.A. Strassenburg put in a plea in 1973 for preparing students for physics-related jobs [15]:

> "In the golden years, applied research simply did not have the same prestige as basic research. This prevented many faculty members who possess the necessary talents and interests from studying applied problems. So the first need is to recognise that any legitimate activity pursued with energy and talent is respectable and if it contributes to the welfare of society, it should be supported and admired.

> I suggest that we allow physics graduate students, once they have satisfied course requirements for Ph.D. candidacy, to satisfy their thesis requirement by working under the supervision of an engineer, a chemist, a geologist or a faculty member associated with one of the special research institutes common on college campuses today."

He added another suggestion:

> "The second suggestion, if implemented, would require greater cooperation with industrial and government laboratories than has been customary heretofore. As long as the quality of the research performed is monitored by a faculty member from the degree-granting institution, I see no reason why a graduate student should not conduct his thesis research in any physics laboratory that has the facilities and personnel to support the kind of applied research he or she would like to pursue."

This is in full agreement with the recommendations of 1968 [11, 7.2. c4, 6; 7.3. b1].

The structure of post-graduate education as well as its length is still much the same now in many countries as it was in 1960 in the United Kingdom [6, p98]:

> ". . . . At least one important point emerges as common to the thinking of industrialists and of many university teachers. This is the need for formal teaching beyond the level of the first degree. A three year first-degree course reaches a level that probably represents the intellectual ceiling of perhaps half of those who graduate . . . . A one-year course of advanced lectures and its associated examination would be expected to lead to a further award, which might be a diploma or an M.Sc. The subsequent period of research for a Ph.D. might be completed by some students in a further 2 years, but it would more commonly be 3 years, making a total of 7 years from first entry to the university."

No significant shift of opinion was observed during the sixties [11, p39]:

> "Industry in Europe and Japan appears to prefer to employ physicists at an early age, i.e. before they have obtained a Ph.D., although it was stressed that some exposure to research, say up to the Master's degree, was desirable. This puts the age of first employment at 25–26 on the continent and at 22–23 in Great Britain and Japan. In contrast American industry wants a physicist to be self-sufficient on his first employment and is prepared to wait for this until he is 26–27 and has his Ph.D."

Many problems are due to insufficient cooperation between industry and university physics departments and to insufficient awareness of the needs [11, p42]:

> "It is appreciated that many of the recommendations are not yet widely accepted by industry in general, which may be unwilling to bear an adequate share of the costs, or indeed by many universities, where physics departments particularly the larger ones, must be made more aware of the problems of industry."

The validity of the above comments concerning work in industry and the preparation of physicists has been acknowledged for many years, but the problems still persist. The frontier is clear: industry on the one side, the universities on the other, although no antagonism is implied in this division.

1.2.1 Problems in the Universities

Turning to problems in the university itself, various quotations will serve to illustrate the position.

P. Klapper wrote in 1959 [25, p37]:

> "The large classes, the inexperienced teachers, the long teaching day, the heavy teaching assignments – these are not the primary causes of ineffective teaching in our colleges and universities today: rather they are the secondary causes which have intensified it. The fact remains that our teachers in institutions of post-high-school levels have not been prepared to teach. We have persisted in the assumption that good teachers are born, hence cannot be made, and, further, that anyone who really knows can teach because the converse – he who does not know cannot teach – is true."

There may be no country where educational abilities are examined on the same professional level as abilities in research. In this respect, there would seem to be little difference between the various countries [5]:

> "The academic ranks in colleges and universities in the United States in order of increasing rank are: graduate assistant, instructor, assistant professor, associate professor and professor. Teaching assistantships and research assistantships are held by graduate students while they work toward advanced degrees. Toward the end of their work as graduate students, some may be appointed as instructors and given somewhat greater teaching responsibilities. Both assistantships and instructorships are appointments for one academic year, renewable at the discretion of the institution. Most Ph.D.'s enter the academic ranks as assistant professors with three-year appointments. After two such three-year appointments, a meritorious faculty member is usually raised to the level of associate professor, after a roughly corresponding period as associate professor, to the rank of full professor.
>
> There are no formal qualifications that must be held before a candidate can be appointed to a post in a British university, although in practice the pattern is fairly clear and generally applicable. Universities aim to recruit their staff from among those who have obtained good 'bachelor' honours degrees and have subsequently taken a Ph.D., but a doctorate is not formally an essential requirement, and, indeed, there are some very distinguished British academic physicists who did not, for one reason or another, take a doctor's degree. The main recruitment of the university staffs is into the lecturer or assistant lecturer grades and promotion is dependent upon ability, particularly ability in research. There is some direct recruitment to the higher posts from physicists who have achieved distinction in industrial or Government research."
>
> There are some signs that the situation may change in the near future.
>
> "We strongly endorse the practice commonly operated in the U.K. which encourages Ph.D. students to assist with undergraduate teaching – tutorials, practical classes and problem classes. This kind of activity is of great value in broadening the Ph.D. student's general knowledge of and interest in physics as a subject." [9, p19].

This recommendation is given a more definite formulation in a paper by N. Peacock [26] on the role of in-service training courses in giving instruction in teaching methods to post-graduate students from developing countries:

> "In training a Ph.D. student, we are often training a future university teacher. There is a very strong case for including students from developing countries in an in-service course. Teaching requirements and teaching methods may vary from country to country, but the basic philosophy remains the same. In addition to providing training for the Ph.D. students concerned, their presence on a course along with new university teachers, and particularly older entrants to the professions who have come from industry, can help the latter to understand the problems of postgraduate students generally and of students from developing

> countries in particular. Thus the training of overseas postgraduate students can aid international academic communications in both directions."

The importance of this for developing countries is especially high but the problem is obviously a general one. In the United States, A.A. Strassenburg answers the question "College physics teachers preparation – how to do it?" by concrete suggestions [20].

The problem should not be neglected by any higher education institution. All too often "A traditional part of the 'education' of a physics graduate student is to face a class as a teaching assistant. Unfortunately the most the new teaching assistant learns from this encounter is how little he knows about teaching." [22].

The general characteristics of the problem are shown in the following [25, p24]:

> "Studies of the supply of teachers for higher education have been few in number and have not been particularly rigorous in their quantitative estimates or adequately analytical in terms of the subject disposition, the quality of teaching and levels of professional competence, or the relationship between supply and standards of university teachers in relation to comparable sectors of the manpower market. Though such questions are integrally linked to any realistic discussion of the need for and the character of new methods of teaching and learning, it is not possible in most countries to move far beyond informed guesswork in this respect; research has neither produced suitable data nor guidelines for applying it to the prospects of changes in teaching and learning methods. This is only one more of the urgent research tasks that a systematic approach to this problem demands."

A need for change is felt and such a change is coming. In the U.K. the Coordinating Committee for the Training of University Teachers indicates an appropriate way through conferences [26] and by stimulating contributions to its newsletter *Impetus* [27]. A fine example is an article by P. Kennedy [27, p12] on the seminar "How to get the best out of University teaching."

A similar trend, even if different in approach and form, may be seen in the U.S.S.R. [23] and other socialist countries [24]. International coordination of these useful efforts seems to be lacking at the present time. Let us hope that in the near future there will be less evidence in support of the statement that much of the teaching in most universities is still largely on an amateur basis [26].

1.3 THE PRIMARY PROBLEM

We have indicated three main professional areas for the physicist. Each raises specific problems in respect of post-graduate education, and one of them is intimately connected with all the others: the problem of the university physics teacher.

Scientific research is carried out in institutions of three different types: (a) the higher education institutions, the universities, (b) the purely scientific institutions, the Academies of Sciences in the socialist countries, le Centre National de la Recherche Scientifique in France, the Max Planck Institutes in the Federal Republic of Germany and so on, (c) certain industrial laboratories of high standard. Physicists active in these institutions are relatively few in number. They are admirably equipped for self-education, and are not only participants but very often initiators of suitable action to promote intellectual productivity, though this does not usually apply in the early stages of their scientific lives, when the influence of their teachers and more advanced colleagues might be determining factors. Here the role of the teacher in recognising talents and developing them in appropriate directions cannot be overemphasised. We must, however, recognise that there are too many university physics teachers who do not feel this to be part of their educational activities, except perhaps in the case of their own research fields.

Effective mutual help between institutions in organizing post-graduate educational activities, defining the objectives and content of courses, organizing summer-schools, seminars, conferences, etc., is of great importance. It is necessary to disseminate good examples by publishing full information on activities, as is organized by le Centre National de la Recherche Scientifique [28] together with similar materials from other countries (the Academies of Science, Max Planck Institutes, etc.). It would seem to be necessary to have means of gathering the necessary data and presenting it in a suitable form. This could be most effective for the participating institutions in providing an exchange of experience. A solution to the problem largely depends on university teachers.

What has been said concerning scientific research in general applies to industrial research and to other professional activities of physicists in industry as well as other professions and disciplines. In contrast to scientific research we find much more heterogeneity in this regard from one geographical region to another. Nevertheless there are many questions common to all countries. One concerns the structure of full-time university post-graduate education in preparation for a career.

The pattern of three-year undergraduate education followed by optional periods of various length and content seems to be advantageous and is probably generally acceptable, naturally subject to modification in the particular conditions of certain countries. The variety of patterns in one- or two-year M.Sc. courses, or their equivalents, is attractive as it makes it possible to tackle the problems of multidisciplinarity, interdisciplinarity and special needs of professions open to persons with basic higher education in physics.

So far no detailed description of any post-graduate education programme seems to have been published, that is to say not just the content of particular courses but a full account of all the activities of staff and students in the educational process. The traditional course, even if developed as described in [25, p158], would be only a part of a desirable programme in post-graduate education. Put like this, the task seems to be an immense one and indeed is. On the other hand, post-graduate education does exist and a great number of physicists enrol every year. Examples, even though not ideal, would be of great help to new higher educational institutions and to those where little experience of post-graduate education has as yet been acquired. In attempting to produce such material, many obvious but not well-defined problems would be identified and hidden problems would also doubtless emerge.

The post-graduate education of physicists, preparing for or working in scientific research in industry or elsewhere, has some features of self-controlled systems. Education reacts to the needs of society and, with some delay, adapts itself to the situation. This is, of course, far from ideal. It seems to be beyond doubt that essential improvement cannot be attained without looking at the main problem, the education of university physics teachers or the self-education of those not limited to traditional thinking. In the widest sense, the crisis in teaching is revealed in the following [25, p36]: "Though marginal adjustments are being made all the time, the essential features of the system persist unaltered. This point comes out clearly when the faculty of any institution begins to consider its teaching problems. The usual point of departure is to consider what can be done to improve the existing pattern, rather than to ask whether the pattern itself requires reform."

Tertiary-level teachers are the only teacher category without a well-established training system. The measures applied in appointing them do not seem sufficiently to stress their teaching abilities and whether or not they are naturally interested in the prospective activities of their students.

There are specific problems at the tertiary level of physics education in applying innovation and progress in the theory of teaching and learning, and also in making contact with the thinking of the younger generation.

With the increased need for tertiary-level physics teachers, with the extension of areas concerned with the discipline of physics and with progress in the theory of teaching and learning, tertiary-level physics teachers should be offered help during their careers by organized forms of in-service training. Physics education lags very much behind physics itself. Every effort should be made to promote the education of tertiary-level physics teachers. This will necessarily open various related questions, but compared with the need to change the present situation of university physics teaching, all other issues are secondary. But what is to be done on a large scale with the primary problem?

Fortunately contemporary trends include features which promise progress and certain lines have already been mentioned.

In the socialist countries, a conference is held every year by the ministers of education and post-graduate education is among the issues discussed [24]. At present, discussion is general but there is no doubt that particular countries will deal with the specific areas more systematically and in detail. At the same time, post-graduate courses, seminars, summer schools and conferences in physics of various kinds are organized by the universities and by the Academies of Sciences, which contribute towards effective progress.

In many countries, as for example in the United Kingdom, initiative lies with the universities, although governmental influence also manifests itself efficiently [10]. It is encouraging to note that great progress is being made in the United Kingdom by the Co-ordinating Committee for the Training of University Teachers. Its activities documented by a conference in 1974 [26] and by the modest but highly commendable newsletter [27] show what is needed. Cooperation of educationalists among themselves, on the one hand, and with students, on the other, concerns more than purely scientific and teaching-and-learning problems. Among others, we should see in these efforts a most serious attempt to reduce and possibly to abolish the stresses between the student and the teacher.

IUPAP and Unesco have already proved on many occasions their interest in, and their ability to promote, the production and world-wide dissemination of materials for the improvement of physics education at national and international level. This applies not only to physics education in general, but also to the specific area of post-graduate education. Concrete suggestions as to how these institutions could organize or coordinate further activities are therefore highly desirable.

1.4 DISCUSSION BY THE WORKING GROUP

Following Cernohorsky, the working group at the Edinburgh Conference interpreted post-graduate education of physicists as any further education of a person awarded at least the first university degree in physics or its equivalent. As such it refers to formal programmes of training leading to degrees such as M.S., M.Phil., M.A.T., Ph.D., D.Sc., etc., as well as to programmes of continuing education designed to assist physicists in industry, secondary schools, colleges and universities in keeping up to date on developments in the field.

J.S. Bruner has written: "I shall take it as self-evident that each generation must define afresh the nature, direction and aims of education to assure such freedom and rationality as can be obtained for a future generation. For there are changes both in circumstances and in knowledge that impose constraints on and give opportunities to the teacher in each succeeding generation.

It is in this sense that education is in constant process of invention." There are two factors of importance to a discussion of education at any level, including post-graduate education. One is the fact that the subject matter area changes – physics itself evolves. The other is that the context in which educational programmes exist changes – societies themselves evolve. There does not appear to be much difficulty with the first factor. Physics as a subject matter area is truly international, people in all countries speak the language of physics fluently, they understand the structure of the subject and follow its changes.

On the other hand, the second factor – the context for educational programmes in physics – appears to differ strongly from one country to another; and in each country to vary with time and on occasion very rapidly. As Cernohorsky remarks, "It is hardly possible to describe the situation in all topical areas and in all countries and to point out all the specific problems connected with the different structures in economics and in culture, in industry and in education, in science and in research of the particular countries . . . . Findings highly relevant for one country may not be applicable in another." Discussion in the working group provided numerous examples of the truth of this statement.

While there are obvious differences of relevance, priority and context in different countries, there are nevertheless some general problems which appear to be shared more or less in common. These derive from the common questions which each country must answer concerning what kinds of physicists and how many physicists it requires and what various kinds of needs it has that physicists can fulfill. This section reports on the group discussions concerning the main career areas in physics and their relations to post-graduate education.

1.4.1 The Main Problem Areas

The working group accepted that the distinct career areas for physicists were (a) as staff members in universities with a primary emphasis on research but with some teaching responsibilities, (b) as teachers in other tertiary institutions, (c) as physicists in government or private research laboratories in which the emphasis is on pure research, (d) as scientists in industry where the research is of an applied nature and in other professions and disciplines.

The traditional forms of post-graduate training have produced people well qualified for areas (a) and (c). Many accounts have been given of such training programmes [5, 6, 8, 9, 29, 30]. In many countries, branching for the various differing career areas occurs early in the programme and is clearly defined. In other countries the education programme is more general and branching occurs later or not at all. The group felt that an up to date comprehensive report on course structures throughout the world would be of value and this is the subject of a recommendation later in this chapter.

As far as the area of pure research is concerned there was general agreement that it was essential to have acquired a sound knowledge of the basic principles of physics together with advanced knowledge and to have demonstrated research capability in a specialized area. A careful balance must be struck between giving a person adequate background and experience and extending the period of formal training to the point where creativity begins to deteriorate. It is important in the training programme to cultivate a spirit of independent enquiry and an ability to continue learning throughout one's career.

A large problem area is concerned with providing training in teaching methods and educational principles for the future university teacher. Numerous references to published articles on this subject are given in the bibliography [17–27]. Traditionally, little attention has been paid to this question although many post-graduate students have in the past obtained, and still do obtain, some experience as instructors, tutors, teaching assistants, etc.

The working group discussed this question at considerable length and agreed, as Cernohorsky has said, that it was essential to pay more attention to the training of university physics teachers. As A. Moumouni (Niger) emphasises, one of the important responsibilities of a university teacher is that he should be able to detect and to encourage the development of the talents of gifted students. No country can afford to ignore this aspect. In Sweden there is a programme for the training of university teachers which consists of a short introductory course, practical guidance during the first year and seminars and short courses in subsequent years. Additional references to reports and surveys carried out in recent years in the U.S.A. are given in the bibliography [31–38].

The need to train physicists for industry has been recognised for some time in many countries. Courses designed for this specific purpose exist at the first degree level in the so-called technical universities, polytechnics and institutes of technology. Less attention has been paid to the need to provide suitable post-graduate training for future physicists in industry. This broad problem was discussed by a conference in 1968 [11] and will be further discussed at a conference planned for 1976 [39]. The bibliography give a number of references on this subject [10–16]. The needs of industry differ widely but there seems to be fairly general agreement that industry wants physicists who are adaptable and who are fairly young.

A number of specific programmes of cooperation between universities and industrial organizations have been developed. B. Ronne (Sweden) has carried out an extensive survey of feedback mechanisms between the labour market and higher education with the aim of designing programmes which fit in better with the needs of employers [40]. In Iraq there is a programme of 'applied research groups', teams made up of both university representatives and representatives of industry, to work on problems of direct industrial interest. This programme has been in operation for two years and the results appear promising. Similar programmes exist in Cuba and Mexico. Several countries allow post-graduate students to do all or part of their thesis work in industry. The working group felt that it would be extremely valuable to have a comprehensive report on such programmes and activities available.

There are several other types of post-graduate training which will almost certainly become much more common in future years. The first of these reflects the need to provide for training in interdisciplinary areas. For example, it may be desirable for a person with a first degree in physics to have some post-graduate training in another science such as biology, geology, or in some business-related area such as economics or management. Such programmes are currently possible in some countries but not in others. The important role that physicists can play in biological research was emphasised.

Another type of post-graduate training is concerned with providing an opportunity for continuing education for people with a first degree in physics who are employed as physicists or physics teachers. Programmes for the in-service training of secondary teachers are discussed elsewhere in this volume. The University of New South Wales in Australia has initiated an interesting course leading to a diploma in 'Current Science', specifically intended for industrial scientists and teachers.

1.5 SUGGESTIONS AND RECOMMENDATIONS FOR THE FUTURE

The working group endorsed the view that the following surveys should be made:

(a) A survey of post-graduate and continuing education programmes for physicists in all countries.

(b) A survey of education programmes for tertiary-level physics teachers in all countries.

(c) Preparation of a model teacher's guide for tertiary-level physics teachers which would help stimulate the production of such guides by each country for its own teachers.

The group was of the opinion that its consideration of the problems of post-graduate education would have been greatly facilitated by the existence of the surveys recommended in items (a) and (b) above and that current surveys of this kind would be of much value to physicists and physics teachers in all countries for purposes of comparison.

It also recommended that there should be summer schools on the education of tertiary-level teachers of physics, both on the national and international level.

As noted earlier, the group gave considerable attention to the question of post-graduate training of physicists in research, both for prospective university physicists and for those in industry. Here again, national and even local boundary conditions will play an important role in determining the nature of possible solutions, but it was the sense of the group that well educated physicists are essential to all countries, and that their training requires the development of an active research atmosphere and of the many and various support functions required to sustain it. Each country also needs to concern itself with opportunities for employment which make good use of the training the physicist has received. Failure to have a good 'impedance match' between training programmes and national needs generally results in much frustration and waste of human and material resources.

The degree of development of technology and industry in the various countries represented covers a broad spectrum. The question of how physicists in one country could make use of the experiences of those in another, of ways in which ideas could be interchanged and in which assistance could be given when required and requested came to the surface often in the group's discussion and brought forth a number of specific suggestions for such assistance.

No physicist can long maintain himself without access to the tremendous and expanding world literature in his field. Nor can an advanced training programme be successful without such access. The provision of adequate library facilities, particularly current technical journals, monographs and textbooks, is a major problem in many countries. The working group strongly emphasised the importance of having at least one really comprehensive library collection in physics and physics teaching in each country and strongly supported the work of international organizations and individual physicists in trying to help countries which request assistance in building such collections.

Two other important areas in which assistance can be provided are those of highly trained manpower and sophisticated scientific equipment. If little or no local expertise is available in a particular area of physics and if a country wishes to develop that area in its educational system, it may, for example, send its students abroad for specialized training, or it may import competent teachers and research workers. In the case of students sent abroad for advanced training, it sometimes happens that the student on completion of the training decides not to return home and this becomes a problem for the student's country. While the ideal solution may be to make return to one's country as attractive as possible, there was a clear feeling in the group that physicists in the country to which the student is sent should be aware of this potential problem and take it into consideration in their interactions with such students.

The group also noted that when a highly trained physicist is invited from abroad to assist in establishing or in developing a programme of teaching and research in a university or of research in industry, every effort should be made to have a proper 'impedance match' between the interests and abilities of the visitor and the opportunities which the host country provides for the visitor to utilize his abilities in a productive way. Not to have a good match of interests and opportunities is once again likely to result in mutual frustration and a waste of scarce human and material resources.

Similar considerations apply to the matter of scientific equipment, especially of a sophisticated type. Even in the most technically advanced countries one can find examples of expensive equipment standing idle in a physics laboratory because no one knows how to use it properly and effectively, or because the technical skill and the necessary spare parts are not available to repair it when it breaks down. The group expressed concern that when sophisticated equipment is provided to countries requesting it, care be taken to see that the expertise and material resources required to keep it operating effectively also be made available. No one can learn from non-operating or non-operable instruments.

Finally the group considered suggestions as to how the recommendations of this and other conferences might be implemented. In addition to the actions which might be taken by national and international organizations (as for example, the programme run by the International Centre for Theoretical Physics at Trieste), it was proposed that more use be made of communication and interactions at what one might call the operating level; in particular, sister-university arrangements and interactions between individual physicists in different countries. The interactions which occurred within the working group itself provided an example of the great usefulness of such interactions, and for many group members this constituted a most important aspect of the Edinburgh conference. The group believed that such arrangements and interactions should be encouraged and facilitated by all countries in the future.

1.6 BIBLIOGRAPHIC REFERENCES

1. Staub, H.H.; Kelly, W.C. Physics Education. *Europhysics News*, Geneva, vol. 4, no. 1, January 1973, p. 1–2.

   A brief account is given of the origin, past achievements and future courses of action of the IUPAP Commission on Physics Education.

   Some of the themes and problems in this publication were related to post-graduate education: education of specialists in physics-related sciences and professions-future engineers, medical doctors, geoscientists, bioscientists, technicians; opportunities for women in physics.

2. Edinburgh International Conference on Physics Education 1975. *Survey of the literature on physics education*. ICPE, 1975, 162 p. Distribution limited.

   Includes (a) detailed annotation of 20 books relevant to physics education published by Unesco, IUPAP and other organizations in the period 1960–1975; (b) lists of books and papers published in 19 countries of all continents in the last five years or so; (c) an additional part comprising papers on physics education [Arab states, Brazil, India, Japan, Libya].

3. *Unesco. University science education improvement – Partial survey of the literature*. Paris, Unesco 1971, 105p. Distribution limited.

   Focuses on science and engineering education as dealt with in the sixties. Annotated bibliography is preceded by analytical sections, none of them devoted to post-graduate education but many particular items bearing on related problems.

4. *Unesco. L'enseignement des sciences dans les universites africaines*. Paris, Unesco, 1964, 122p. Rapport du Stage sur l'enseignement des sciences fondamentales dans les universites africaines [Rabat, 13–22 decembre 1962].

   Important facts and views to be borne in mind in planning the building-up of post-graduate education in developing countries, even though the book pays very little explicit attention to the problem.

5. Unesco. *A survey of the teaching of physics at universities*. Paris, Unesco, 1966, 396p.

   Prepared under the auspices of IUPAP. Contains surveys of the situation in the early sixties in Czechoslovakia, Federal Republic of Germany, France, U.S.S.R., U.K. and U.S.A. Information concerning post-graduate education is given in chapters on the advanced study of physics leading to higher degrees, academic research in physics, special programmes in physics (continuing education, evening schools, extramural education) and teachers of physics in universities.

   Many details have changed during the last decade, but the main features of the structures seem to have been preserved.

6. Brown, S.C.; Clarke, N. (eds). *International education in physics*. New York, Technology Press and John Wiley and Sons, 1960, 191p.

   Contains the proceedings of the first International Conference on Physics Education held at Unesco in Paris in 1960 under the auspices of the International Union of Pure and Applied Physics. It was this conference that led directly to the establishment of the IUPAP Commission on Physics Education.

   The chapter "The post-graduate training of physicists" deals with the systems in the U.S.A. and in the U.K.

7. Brown, S.C., Clarke, N. (eds). *The Education of a Physicist*. Edinburgh, Oliver and Boyd, 1968.

   A report on the International Conference on the Education of Professional Physicists, London, July 15–21, 1965.

8. The Institute of Physics and The Physical Society. *The Scientific Education of Physicists*. IPPS, London, 1965. 59p. Booklets concerning IPPS and its activities. Booklet 8.

   A guide for students and for those who have the responsibility of advising them or teaching them.

   Includes a brief account of the system of post-graduate education in British universities in the mid-sixties.

9. United Kingdom. The Royal Society. *Postgraduate Training in the United Kingdom. 2. The Training of Ph.D. Students in Physics.* London. The Royal Society, 1968, 33p.

   Prepared by the Physics Subcommittee of the Royal Society's Committee to Examine Post-graduate Training in Science and Technology.

   Existing course arrangements and examinations are outlined. Graduate schools in the U.S.A. are compared with post-graduate training establishments in the U.K. Course work, Ph.D. theses and examinations are critically examined. The main recommendation stresses the usefulness of developing post-graduate courses given specifically for Ph.D. students.

10. Flowers, B.H. *Science, industry and government*. Nature, London, vol. 222, no. 5192, May 3, 1969, p. 421–425.

    Traces the history of Government involvement in science and industry and describes some schemes of the Science Research Council for encouraging more scientists to enter industry. Relevant views on content and organization of post-graduate education.

11. Diemer, G.; Emck, J.H. *The education of physicists for work in industry*. Eindhoven, Centrex Publishing Company. 55p. Proceedings of an International IUPAP/Unesco Seminar held at Eindhoven, The Netherlands, 2–6 December 1968.

    Results of a comprehensive analysis of the topic. A great deal of the content concerns various periods and forms of post-graduate education.

12. Diemer, G., Emck, J.H. *The education of physicists for work in industry*. Eindhoven, Centrex Publishing Company, 1969. 266p. Source Book of papers and statements prepared for the 1968 Eindhoven IUPAP/Unesco Seminar.

13. The Committee of Vice-Chancellors and Principals of The Universities of the United Kingdom. *Schedule of Post-graduate Courses in United Kingdom Universities*. 1969–70. London. 98p.

    More than 70 one- or two-year M.Sc. or Diploma full-time courses of formal instruction in physics are scheduled.

14. Jansen, L. More physicists than jobs in the USA: a lesson for Europe. *Europhysics News*, Geneva, vol. 2, no. 6, August–September 1971, p. 1–3.

    Difficulties during the period 1967–1970 are analyzed. Some statements are of general value in respect of post-graduate education of physicists, irrespective of the geographical area or of the economic structure in the particular country.

15. Strassenburg, A.A. Preparing students for physics-related jobs. *Physics Today*, New York, vol. 26, no. 10, October 1973, p. 23–29.

    To keep pace with the changing times, physics departments should offer courses and major curricula in interdisciplinary fields, as well as encourage more applied research. Some problems of post-graduate education are indicated explicitly, others may be deduced from ideas concerning physics teachers at all levels.

16. Casimir, H.B.G. Technology for the future. *Europhysics News*, Geneva, vol. 5, no. 9, September 1974, p. 1–6.

    Lecture given in 1974, at Amsterdam, during the Euro-con congress 'The engineer in society.' Post-graduate education of physicists is not discussed directly, but the problems indicated are very closely connected with such education.

17. Kapitza, P. Science teaching and scientific method. *The Physics Teacher*, New York, vol. 9, no. 8, 1971, p. 429–434.

    Opening address by P. Kapitza delivered at the IUPAP/Unesco International Congress of Physics Teachers held at Eger, Hungary in 1970. The sociological aspects of physics education are dealt with. Involvement of post-graduate students and scientists in educational activities is proposed in the section on 'Problems of Teaching.'

18. Price, J.E. Acceptability of the Doctor of Arts degree in physics. *American Journal of Physics*, New York, vol. 39, no. 11, 1971, p. 1300–1302.

19. Byrd, J.W.; Adler, C.C. A profile of the two-year college physics teacher. *American Journal of Physics*, New York, vol. 39, no. 11, 1971, p. 1302–1306.

20. Strassenburg, A.A. College physics teachers preparations – how to do it? *American Journal of Physics*, New York, vol. 39, no. 11, 1971, p. 1307–1310.

21. Muhlestein, L.D.; DeFacio, B. Teaching graduate teaching assistants to teach. *American Journal of Physics*, New York, vol. 42, no. 5, 1974, p. 384–385–386.

    Describes a course entitled 'Study of Techniques of Teaching College Physics' required of all first-year graduate teaching assistants. As a principal feature of the course, graduate students improved existing laboratory experiments or developed new ones.

22. Spears, J.; Zollman, D. Orientation for the new teaching assistant – A laboratory based program. *American Journal of Physics*, New York, vol. 42, no. 12, 1974, p. 1062–1066.

    One week before the beginning of classes, the new graduate teaching assistant attends a five-days laboratory instructors orientation programme. The programme includes introductions to Transactional Analysis and Piaget's theory of intellectual development.

23. Jeljutin, V.P. *Organizace vyucovaciho procesu a jeho rizeni na vedeckem zaklade* (Organization of the instruction process and its control on a scientific basis). Czech translation from the Russian. Prague, Ministry of Education, 1972, 15p.

    Report presented by the delegation of the U.S.S.R. at the seventh conference of the ministers of education of the socialist countries, Prague, 1972.

    Contains results of quantitative studies on various components of the educational process in institutions of higher education. No special items on post-graduate education of physicists are included, but many facts and ideas are stimulating in respect of possible forms of organization of effective education on a large scale.

24. International journal of socialist countries *Sovremennaia visshaia shkola* (Contemporary higher school – Contemporary higher education), Warszawa, vol. 1, no. 4, 1973, p. 117–191.

    General survey of the post-graduate education in particular socialist countries.

25. MacKenzie, N.; Eraut, M.; Jones, H.C. *Teaching and learning. An introduction to new methods and resources in higher education*. Paris, Unesco and The International Association of Universities, 1970. 3rd impression 1972, 209p.

    A work of wide scope, ranging from the theoretical background to the technique of developing courses. A unique presentation of relevant facts, opinions, suggestions and recommendations. Most chapters offer useful suggestions for tackling the problems of post-graduate education of physicists.

26. Main, A.N. (ed). *Papers for the Manchester Conference 7–9 June 1974*, Glasgow, The Co-ordinating Committee for the Training of University Teachers, 1974. 61p. Distribution limited.

    Pre-conference materials grouped under the headings Objectives, Content, Methods. Without discussing the post-graduate education of physicists as such, many of the papers deal with the activities of university teachers in general.

27. United Kingdom. Glasgow. The Co-ordination Committee for the Training of University Teachers. *Impetus*. Newsletter of CCTUT.

    Informal newsletter containing stimulating information, notes and opinions.

28. France. Centre National de la Recherche Scientifique. *Formation post universitaire au Centre National de la Recherche scientifique*. Paris, 1975. 2p. Distribution limited.

    A two-pages report summarizing the activities of the C.N.R.S. in post-graduate education with special attention to physicists.

29. *Physics Courses in Higher Education*. Institute of Physics, London.

30. *Research Fields in Physics in U.K. Universities and Polytechnics*. Institute of Physics, London.

31. The Training of Graduate Student Teaching Assistants, Frank Koen, *Educational Record*, Winter 1968, p. 92–102.

32. *Preparing Two-Year College Physics Teachers: A Workshop Report*. A report of a Commission on College Physics Workshop held at SUNY-Stony Brook in August 1969. Discusses characteristics of students and teachers in the two-year colleges and possible programmes for training teachers for these colleges. Some copies available from the American Association of Physics Teachers.

33. *The Missing Component – Graduate Preparation for Teaching*. A report of a national conference held in 1969 and four regional conferences held in 1970 and 1971, by the Commission on College Physics. Report published in February, 1972. Proposes and provides some examples of programmes designed to improve the teaching ability of the physics graduate student teaching assistant. Some copies available from the American Association of Physics Teachers.

34. *The Graduate Preparation of Scientists for Undergraduate Teaching in Liberal Arts Colleges and Universities*. Report of a conference held in May 1969, under the auspices of the Association of American Colleges and the Council of Graduate Schools in the United States. Published 1970. Discussion of alternate degrees and some specifics of possible programmes.

35. *Graduate Teaching Assistants in American Universities: A Review of Recent Trends and Recommendations*. U.S. Office of Education Report OE-58039 by John L. Chase, May 1970.

36. Scientific Manpower: A Dilemma for Graduate Education. Edited by Sanborn C. Brown and Brian B. Schwartz. *M.I.T. Report No. 22*, The MIT Press, Cambridge, Mass. 1971. A report of a symposium held at MIT in May 1970 under the title of The Supply, Need and Utilisation of Graduate Scientists and Engineers.

37. *Physics in Perspective*. The report of the Physics Survey Committee N.R.C. – N.A.S. published by the National Academy of Sciences, Washington, D.C. Volume I (1972) contains a chapter entitled Physics in Education and Education in Physics which presents a general discussion of these topics. Volume II (1973) Part B, contains a chapter entitled Education, which presents an extended discussion of graduate education.

38. Report on the Conference on Tradition and Change in Physics Graduate Education. Alex E.S. Green, *American Journal of Physics, 43*, 214, (1975). A report of a conference held at the Pennsylvania State University in August 1974, under the auspices of the Forum on Physics and Society and the Committee on Education of the American Physical Society, jointly with the American Association of Physics Teachers.

39. Conference on Physics and Industry. Dublin, Ireland, 9–13 March 1976 (organised for IUPAP by the National Committee for Physics of the Royal Irish Academy).

40. An account of this work is scheduled for publication. Details may be obtained from Dr B. Ronne, Office of the Chancellor of the Swedish Universities, P.O. Box 16334, S-103 26 Stockholm 16, Sweden.

41. *Some notes on the Evolution of Graduate Education in Physics in the U.S.A.* E. Leonard Jossem, Department of Physics, The Ohio State University, Columbus, Ohio, U.S.A. Brief notes prepared for the I.C.P.E., Edinburgh 1975. Copies may be obtained on request from the author.

2 Physics curricula and courses for physics undergraduates

This chapter, written originally by P.J. Black, gives an account of physics curricula for courses leading to a first degree with physics as the main subject. Information about the structure of the curricula, the content, length and arrangement of courses, is given for first degree courses in twelve universities in nine different countries. The pattern of employment of graduates in these countries is also discussed. A second main section of the paper gives a brief general survey of the data and then discusses three main problems – coherence and structure in the curriculum, the relationship of employment needs to the aims of the courses, and the need to reduce the content and level of sophistication of curricula so as to promote better education in physics. The final section reports the thoughts expressed by the working group in discussion.

2.1 INTRODUCTION

This chapter contains three main parts. Section 2.2 presents a factual survey of undergraduate curricula. Section 2.3 contains a discussion of some of the issues raised and Section 2.4 gives the findings of the working group. The information presented here has been collected by correspondence with colleagues in twelve universities and is supplemented by reference to published literature. The information selected for presentation has been limited to physics courses which form part of a curriculum leading to a degree in which physics forms the sole or the major component and is linked to presentation of data about the employment of first degree graduates. The problems of teaching physics to those not specializing in physics are ignored, and there is no particular concentration on the basic courses which are often taken jointly by specialists and non-specialists or which are taken before decisions to specialize are made.

In Section 2.3 the discussion will draw attention to limitations of the survey which arise because it is of necessity very general and makes a rather superficial examination of the learning and teaching work in undergraduate courses. However, some of the problems of curriculum design are illustrated by the evidence and some of the fundamental problems concerning the aims and level of sophistication of first degree courses, are discussed.

2.2 A SURVEY OF UNDERGRADUATE CURRICULA

In the tables reproduced in this Section the following abbreviations are used. P always stands for physics, Q.M. for quantum mechanics, S.S.P. for solid state physics, P. of M. for properties of matter, E. and M. for electricity and magnetism, and N.P. for nuclear physics.

2.2.1 Two Universities in the United Kingdom

Students enter first degree courses at age 18 after rather specialized study in the last two years at school during which 50 per cent of their time is devoted to physics and mathematics. Most first degree courses take three years, but a student in physics and mathematics is on entry about a year ahead of most students entering universities in U.S.A. and Europe. About 15 per cent of physics students are women. The curriculum at Birmingham is shown in Table 1. Students choose this course if they wish to specialize in physics, but after two years of concentration on physics and mathematics they can choose in their third year to broaden their study into other disciplines. Tutorial teaching accounts for between 25 per cent (1st year) and 15 per cent (2nd year) of the course hours.

Table 1
Curriculum at Birmingham (U.K.)
Numbers in brackets are hours of teaching

First Year (440–95%)					
Mathematics	(100)	Atomic	(25)	Relativitity	(15)
Laboratory	(115)	E.M. Fields and Circuits	(50)	Statistics	(10)
Lab. Projects	(15)	Mechanics	(35)		
Computing	(30)	Optics	(35)		
Second Year (435 to 475–95%)					
*Mathematics	(20)	Waves	(15)	*Thermal[3]	(40)
Laboratory	(105)	*Q.M.[2]	(30)	P. of M + S.S.P.	(35)
Lab. Projects	(95)	Atomic	(25)	Circuits and Electronics	(10)
		*E.M. Theory[1]	(30)		
Options – advanced work in courses marked (*) and/or extra courses in–					
		Physics of Music	(15)	Electron Physics	(15)
		Analysis of Materials	(15)	Low Pressure Gases	(15)
Third Year (435 to 510–100%)					
Laboratory	(140)	Nuclear[5]	(35)	S.S.P.[4]	(35)
Project Lab. + Theory	(140)				
Options – one or two from					
		Astronomy and Astrophysics		(80)	
		Theoretical		(80)	
		Other discipline (Biology, Geophysics, Electrical Engineering)		(80)	
		Advanced topics Nuclear, or S.S.P. or Quantum Optics		(80)	

Typical Textbooks

[1] Feynman Lectures II;
[2] Merzbacher, Quantum Mechanics;
[3] Berkeley V, Statistical Physics;
[4] Kittel, Solid State Physics;
[5] Cohen, Nuclear Physics.

There are links between courses in any one year e.g. relativity is taught late and builds on ideas developed in all four preceding courses in the first year, while second year atomic physics uses results of the quantum mechanics. Plans for related courses in successive years (e.g. electromagnetism years 1 and 2, electric circuits years 1 and 2) are also coordinated. Some features (e.g. teaching of wave motion in year 2) are explained by the need to follow appropriate mathematics.

Year 2 is difficult because most of the fundamental aspects are treated, but this means that year 3 can allow wider choice, discuss applications and include sophisticated projects. The course is essentially designed to train the specialized professional physicist and about 60 students graduate each year.

The curriculum at Chelsea College, London, is illustrated in Table 2, but, in contrast to Table 1, this only shows the main aspects of the course taken by a typical student specializing in pure physics rather than the single course taken by a whole group. The general rules of the University of London are that a degree is granted on a minimum of 9 courses taken and 8 passed: good students pass 11 or 12. The maximum in any one year is 4.

Table 2
Curriculum at Chelsea, London (U.K.)
Numbers in brackets are course units

First Year

Mathematics (1) Mechanics, Atomic, Nuclear (¾) Electricity (½)
and *either* Further Maths. or Chemistry or Electronics or Earth Sciences (1 or 1¼).
and optional extras in other science or non-science areas.

Second Year

Mathematics (½ or 1) Electromagnetism (½) Q.M. (½) Thermodynamics (½)
and one or more of (Mechanics (½) Optics (½) S.S.P. (½)
(usually four) (Nuclear (½) and Essay + Project (½)

Third Year

Best students would take the first two and five or six more of these courses

Applications of Electromagnetism (½) Essay and Project (½) E.M. Theory (½) Statistical Mechanics (½) Q.M. (½) S.S.P. (½) Vibration P. (½) Optical Systems (½) Acoustics (½) Computers (½) Applied N.P. (½) Further Maths. (½) Physical Environment (½) Energy and Environment (½)

A course unit may include lectures (between 36 and 24 hours) associated tutorials and relevant laboratory work: the only separate laboratory work in Table 2 appears under projects. The unit system allows a wide variety: at the end of year 1 a 'physics' student may transfer into one of four different joint courses and the balance of his specialization can be altered in more subtle ways by the width of choice. One difficult task is the construction and interpretation of rules for assigning the name of a student's degree (Physics, Physics with Electronics, Physics and Electronics all denote different mixtures). A disadvantage is that students have relatively few units in common, which inhibits cross-links between courses and prevents the design of a course as a coherent whole. Colleges in London can present more restricted ranges of choice if they wish: one discussion of a system which offers a set of only four combinations for physics specialists is given by Jones [14].

A detailed survey of a few courses is given in Chapter III and Appendices IIIE of the 1966 Unesco survey [20] whilst a general review of first degree courses in the United Kingdom is available [7]. Numbers of entrants have been fluctuating since 1967 without significant increase. The main trends, to increase the range of options and of mixed discipline courses, are illustrated, in different ways, by the examples discussed above. Data on careers for graduates have been presented by Ebison [9]. Of the 2000 who take physics degrees each year, about 30 per cent undertake M.Sc. or Ph.D., 15 per cent enter teacher education courses and 45 per cent enter employment, most of them in the U.K. Of this latter group, in 1973, 41 per cent were engaged in scientific research, development or design, 24 per cent in management, management services or general training, 12 per cent in production, buying, marketing and selling and 12 per cent in financial, legal and patent work. The proportion of graduates entering M.Sc. or Ph.D. work has declined recently and the range of employment undertaken by graduates has expanded; these trends are making it essential to consider the value of courses designed primarily for professional work in pure physics.

2.2.2 Two Universities in the United States of America

Details of the curriculum at four universities in the U.S.A. were given in Chapter III and Appendices IIIF of the 1966 Unesco survey [20]. Similar and more recent data for nine institutions were surveyed in a set of articles in *Physics Today* in 1968 [2]. Data on courses in two institutions have been collected for this article. These will be presented first and will be followed by a more general discussion.

Most students enter degree courses at age 17 to 18 having completed at least one year of high school physics – a substantial fraction having taken P.S.S.C. or Project Physics. About 9 per cent of those graduating are women. High School mathematics usually stops short of calculus. Most students take four years to complete a first degree.

Students specializing in physics at the Massachusetts Institute of Technology have to spend about 20 per cent of their total time on humanities courses and about 7 per cent on sciences other than physics; they may, in addition, devote about another 15 per cent of the time assigned for free 'electives' on non-physics courses if they wish. The data in Table 3 do not show any of the non-physics work apart from the required minimum of mathematics courses. The basic pattern of this course consists of rather general study in the first two years, in each of which only about half the time is spent on physics and mathematics, with a more sophisticated course for the last two years in which coherence is obtained by the linked sequence of theoretical courses together with the required course in quantum physics.

However, it is possible to obtain a physics degree with a minimum of two options in (say) astrophysics and statistical physics in years 3 and 4, so avoiding any mechanics or electromagnetism in those years. There is heavy emphasis on problem-solving, particularly in elementary courses, and the class hours quoted for a typical course would be divided into two hours of tutorial sessions for every three hours of lectures. There is considerable emphasis on laboratory projects. Coordination of physics with mathematics is a major problem and there are plans to remedy the absence of required course work in thermodynamics (in physics) by a revised statistical physics course.

Electronics is covered in laboratory and in engineering options. Comparisons with the 1966 Unesco survey show some alterations (e.g. linking vibrations, waves, optics in one course, linking relativity with mechanics, removing heat from elementary courses) but no fundamental changes. M.I.T. has about 90 physics graduates in any one year – the largest number for any institution in the U.S.A.

Table 3
Curriculum at Massachusetts Institute of Technology

Numbers in brackets are hours of class teaching

Year 1.			
Mathematics	(120)	Mechanics + Relativity[1] Electromagnetism[1]	(60) (60)
Year 2.			
Mathematics Project Laboratory	(60) (75)	Vibrations, Waves, Optics[2] Introductory Quantum Physics	(60) (60)
Years 3 and 4.			
Mathematics	(120)	Quantum P of Atoms and molecules[3]	(60)
Laboratory (Year 3) Lab. Project (Year 3) Thesis (usually experimental project in Year 4)	(110) (40) (75–150)	Options (minimum 2; most take more) Three in Theoretical Physics (Advanced Mechanics[4] (60), E.M. Theory (60), Statistical Mechanics (60), which form a 3-semester sequence) S.S.P. (60) Nuclear (60) Plasma (60) Astrophysics (60) and others.	

Typical Textbooks

[1] Halliday and Resnick,
[2] French, Vibrations and Waves.
[3] Eisberg.
[4] Marion and Landau and Lifshitz.

The curriculum at Ohio State University is surveyed in Table 4. Although this is a large university (about 50 000 students), the number enrolled for introductory physics courses is about 2 900 whilst the number completing a first degree in physics in any one year is about 30. The curriculum shown would be recommended for a student specializing in physics; for a bachelor degree not more than 75 of the total credit hours (between 147 and 195) may be taken in any one department. The physics component builds up from a general course in the first year, through courses which are phenomenological rather than theoretical in year 2, to linked sequences of courses in the final years. For example Fields and Waves I, II, and III deal respectively with electric fields; magnetic fields, Maxwell's equations, waves, and special relativity; waves in matter, physical optics. By leaving out the last parts of these linked sequences and laboratory work, time can be made to combine physics with a substantial study of another theme.

Another main combination can be obtained from physics and engineering courses by removing some advanced and laboratory physics to give 55 physics credits which are combined with about 30 credits chosen to form a coherent sequence from amongst six engineering disciplines. The basic physics strategy has been to provide a coherent core which can be supplemented in a variety of ways. Laboratory work receives considerable emphasis, and in each laboratory a student completes four open-ended experiments in a period of ten weeks.

These two examples may give some of the flavour of the degree courses in the U.S.A., but cannot convey the wide variety. The articles in *Physics Today* (March 1968) [2] provide evidence of the latter. For example, there are courses which follow two years of general physics with two years concentration on tough theoretically based courses (Reed), courses in which chemistry and physics are taught in combination for a first year or in sequence over the first two years (Reed, Chicago), courses in which the 2 + 2 model is replaced by one year of general physics, followed by three years in which each topic is taught once and for all to give a linear rather than spiral sequence (Princeton). Each of these patterns illustrates a different response to the curriculum problem. However U.S. colleges and universities also devote much attention to curricula for teacher education and for careers other than pure physics and this paper cannot do justice to the wide range of these 'second track' programmes.

Table 4
Curriculum at Ohio State University

Numbers in brackets are credit hours
(1 credit hour = 1 hour per week for 10 weeks)

Year 1		
Mathematics	(15)	*Particles, Motion (5); Waves, Quanta (5) *Particle Systems Electrodynamics (5)
		Other courses (English, Languages, Physical Education, Electives) (24)
Year 2		
Mathematics	(10)	Gases Liquids Solids[2] (3), Quantum Phys.[3] (3)
Laboratory	(4)	Other courses (Chemistry (10) Science Electives (5), Foreign Language (10), Biology (5), Other Electives (6 or more))
Year 3		
Mathematics	(10)	Dynamical Models[4] (4+4); Stat. Mechanics[5] (4)
Advanced Lab.	(3)	Fields and Waves I and II[6] (4+4)
Seminar	(1)	Other courses (Liberal Arts topics) (20)
Year 4		
Advanced Lab.	(3)	Fields and Waves III[6] (4)
Seminar	(1)	Structure of Matter I, II, III[7,8] (4+4+4)
Electronics for Physicists (mainly Lab.)	(5)	Physics Electives (5) Thermodynamics (4) or choice of courses, each of 3 units, in Nuclear, Solid State, Plasma, X-ray, Molecular Spectra Elementary Particles. Other courses (Liberal Arts (14)) Other Electives (10)

Typical Textbooks

[1] Shortley and Williams,
[2] Flowers and Mendoza,
[3] Tippler,
[4] Symon,
[5] Sears, Thermodynamics and Statistical Mechanics,
[6] Lorrain and Corson,
[7] Park, Intro. to Quantum Theory,
[8] Laighton, Principles of Modern Physics. *Plus Associated Laboratory.

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The employment pattern for first degree graduates in the U.S.A. may be followed in the American Institute of Physics Manpower Reports [3] [4]. The number of those specializing in physics has fallen steadily from a peak of 6 000 in 1969 to 4 700 in 1974 although the number is now expected to level out. Of the 1974 graduates about 34 per cent went on to graduate study in physics and a further 25 per cent to graduate study in other fields (engineering, medicine and astrophysics/astronomy together account for half these). The physics graduate study dipped from 55 per cent in 1966/7 to 30 per cent in 1971/2 and has now risen again. Thirty-six per cent were going to full-time employment (a proportion which has fluctuated from 22 per cent in 1966/7 to 40 per cent in 1972/3) and of those about 1 in 5 was not in employment at the time of the survey; the employment situation for graduates has improved steadily from a low point in 1971. Of those in new employment, 14 per cent were in teaching, 47 per cent in research and development or engineering, 10 per cent in computer programming, 4 per cent in management training, and a further 7 per cent in some form of skilled work. Only a small proportion (13 per cent) of those in employment felt that they were making no use of their physics training, whilst a further 44 per cent felt they were making little use of it.

2.2.3 The University of New South Wales, Australia

Students enter courses at age 18 after passing a school examination in four subjects, and although most can handle calculus on entry their standard in physics is closer to that of students in the U.S.A. rather than in England. The physics course in the University of New South Wales requires three years for a pass degree and four years for honours. Table 5 outlines the curriculum for a four year honours course, and shows that the proportion of time devoted to physics in successive years is about 25 per cent, 50 per cent, 100 per cent and 100 per cent.

Laboratory hours are linked with courses in the first three years and the course hours include lectures and tutorials: in the first year there is one tutorial (groups of 16) to every three lectures (groups of 150 to 350). In 1973 there were 39 third year and three fourth year students. The number in fourth year degree courses in physics for Australia as a whole reached a peak of 169 in 1967 and was 122 in 1973, whilst corresponding figures for third year courses were 431 (in 1968) and 387 (1974): detailed figures are in the 1974 article by Watson-Munro [22]. The Colleges of Advanced Education also train a significant number of graduates [18].

A survey of the Australian Department of Labour [6] shows that in 1973 half of the country's physicists were under 30, 90 per cent were under 50, over 60 per cent worked in government (Commonwealth or State) laboratories and another 33 per cent worked for academic institutions. While the country's stock of qualified physicists is expected to double in the next decade, very few vacancies exist in any of the areas of professional scientific work apart from secondary school teaching. Very few physicists are employed in industry, and the small size of Australian-owned companies, together with the subsidiary nature of research by multi-national companies, make it unlikely that demand for physics graduates will grow. The expansion over the past decade in tertiary education and government research is unlikely to continue. Thus, for the first time a large proportion of physics graduates may have to seek work either in areas where their training will not be directly used, or in technical work for which Australian industry traditionally uses engineers and almost no physicists. The University of New South Wales is trying to respond to this problem by creating an industrial stream in the third and fourth year courses, overlapping with the present course but more involved with industrially useful topics both in lectures and in laboratory experiments. Many industries have welcomed the plan and have promised cooperation.

Table 5
Curriculum at the University of New South Wales
Numbers in brackets are hours of teaching

Year 1		
Mathematics	(140)	Mechanics, E and M, D.C. circuits, Physical Optics, Heat, Modern Physics (112) (Higher level course available with A.C. and electronics in place of heat and modern physics). Other courses Chemistry (168) One other science (168)
Laboratory	(25)	
Year 2		
Mathematics	(56)	Electromagnetism[1] (42), Quantum Physics[2] (42) Thermodynamics[3] and Mechanics[4] (56) (Lower level courses available in two of these topics but Quantum Physics replaced by Modern Physics[5]) Other courses (Five further units to be chosen from other sciences)
Laboratory (for E and M and Q.P.)	(84)	
Year 3		
Laboratory – on each of 4 core courses (4 x 42 = 168) plus on each elective (up to 4 x 56 = 224)		Q.M.[6] (42), E.M. and Statistical Mech. (42) S.S.P. and N.P. (42), Atomic P and Spectroscopy (42). And a choice of up to 4 options from: Electronics (28) Biophysics (28), Solid State devices and Electronics (28), Conceptual framework of physics (70 – no lab.), Marine acoustics and seismic physics (28).
Year 4		
Project in research group		Atomic and N.P. (26), Q.M. (26), S.S.P. and magnetism (26), Statistical P. (26)
Seminars and tutorials	(56)	

Typical Textbooks

[1] Carson and Lorrain,
[2] Eisberg,
[3] Reif,
[4] Symon,
[5] Eisberg,
[6] Schiff

2.2.4 The University of the West Indies, Jamaica

Most students enter for a four year course although it is possible to enter at year 2 level (with the equivalent of an English entry standard in physics). Full data on non-physics courses and on laboratory work are not given in Table 6 but all students are required to pass courses in English, Development of Civilization and History of the Caribbean. Of the course hours shown, 1 in every 6 is a tutorial, the other 5 are lectures. The curriculum in Table 6 is for a 'general' degree, taken by about 30 students each year. There is also a 'special' degree for which some of the second- and third-year courses are taken in an earlier year and the students' third year is devoted to more advanced courses (e.g. Quantum Mechanics using Schiff as a textbook): about three students per year take this course.

Table 6
Curriculum at the University of the West Indies
Numbers in brackets are hours of teaching

Year 1	
Introductory courses in Mathematics and Physics[1]	
Year 2	
General Physics course[2], using calculus, some emphasis on Rotational Kinematics, Physical Optics, Modern Physics and A.C. Theory.	
Year 3	
Laboratory (150)	Oscillations, Waves (24) A.C. Electronics (24) Modern Physics (24) Thermodynamics (24) plus 3 from a set of 11 options each of 12 hours.
Year 4	
Either **Physics**	11 or 12, 12-hour units, 6 in E.M., Q.M.[4], S.S.P., Atomic P.[3] Statistical Mechanics, Optics and the rest chosen from a list of 22 options, many of them on applied topics.
or **Applied Physics**	11 or 12, 12-hour units, 8 of which have to come from one of three coherent groups on Electronics, Communications, Materials Science or an 11 unit group on Applied Solid State Physics.

Typical Textbooks

[1] Sears and Zemansky, College Physics;
[2] Halliday and Resnick,
[3] Semat and Albright, Atomic and N.P.,
[4] Beiser, Concepts of Modern Physics.

Detailed data on careers are not available, but graduates do find employment in teaching, in local industry and government science, in industrial and business management or in other fields not directly using their physics qualification. The main concern with the curriculum at present is to relate it to needs of local society: the options in applied physics serve this purpose and have been based on surveys carried out with local industry. Some post-graduate work is similarly directed, e.g. use of local fibres in materials science or the effect on rainfall of burning of sugar-cane. There is a concern to alter the local reputation of physics – that it is a difficult and aloof subject – without lowering standards and while maintaining a special degree course for the able dedicated physicist. The breadth of topics in the general degree curriculum reflects the main concerns with applications and means that substantially less time is spent on the main theoretical elements of physics than in many of the other courses reported here.

2.2.5 The University of Rio Grande do Sul, Brazil

Students enter a four year course at ages 18 to 19. There are about two candidates for every place available in physics. Teaching in each year takes place over two semesters each of 15 weeks, and all of the courses shown for years 3 and 4 in Table 7 last for one or two semesters.

Table 7
Curriculum at the University of Rio Grande do Sul Brazil
Numbers in brackets are hours of teaching

Year 1			
Mathematics	(180)	Introductory Physics[1]	(180)
Year 2			
Mathematics	(180)	Introductory Physics	(90)
Computers	(90)	Mechanics[2]	(120)
Years 3 and 4			
Laboratory	(360)	E.M. and Optics[3] (180), Electronics (90), Thermodynamics and Statistical Mech. (120), N.P. (120), S.S.P. (120), Q.M.[4] (180)	
		Students are also required to take some options in any other University Department.	

Typical Textbooks
[1] Halliday and Resnick,
[2] Kibble,
[3] Corson and Lorrain, Klein
[4] Schiff

There are two main physics courses, one in pure physics and the other for future high school teachers: the latter is not presented in Table 7 – it differs in years 3 and 4 by replacing many of the physics courses and half of the laboratory work by courses and practical work in educational topics. Of the 80 students admitted each year, less than half take pure physics and only 30 to 40 per cent graduate after four years. There is a trend at present to put more emphasis on laboratory training since the courses used to be strongly theoretical. In their last year, students often obtain student fellowships to help in introductory teaching or to take part in research work.

Nearly all pure physics graduates enter graduate studies for M.Sc. and many go on to Ph.D. work. The course is designed exclusively for training future physicists and almost the only employment for the graduates is in the university: however, this market will become saturated. All of the courses have extensive and high level content and it is reported that much of this is not assimilated by the majority of students.

2.2.6 Two University Courses in India

Students enter university courses in India at ages 16/17 after a secondary course in which many will have taken about eight subjects in the final secondary examinations. B.Sc. courses take three years and students graduate at ages 19/20. The number of women students is between 5 per cent and 10 per cent in the two universities discussed below.

At Aligarh Muslim University, the specialized degree is built up from 120 credits of which 48 are in physics, 32 in mathematics, 16 in chemistry and 24 in general and compulsory courses. Each course is completed within one semester. It can be seen from Table 8 that only in the third year is as much as 50 per cent of the total course work devoted to physics. Most courses in the last year are primarily designed for students going on to a M.Sc. course. The detailed design of the various courses is strongly influenced by the need to link to corresponding mathematics courses. An important structural weakness is said to be the lack of inter-connecting links between the courses.

Table 8

Curriculum at Aligarh Muslim University India

Numbers in brackets are course credits. A Complete course is 40 credits per year

Year 1		
Laboratory	(4)	D.C. Circuits (2), Optics (2), Wave Motion (4) Together with Mathematics and Chemistry
Year 2		
Laboratory	(4)	Heat and Thermodynamics[4] (4), Physical Optics[1] (4) Properties of Matter (4) Together with Mathematics and Chemistry
Year 3		
Laboratory	(4)	A.C. and Electronics (4), Modern Physics[2] (4), Structure of Matter (4), E. and M.[3] (4) Together with Mathematics

Typical Textbooks

[1] Sears, Optics;
[2] Schiff, Q.M.;
[3] Scott, Physics of E. and M.
[4] Zemansky; Halliday and Resnick for several courses.

The course at the Jamia Millia Islamia in Delhi has a similar overall pattern. Of the hours shown about one in five is devoted to tutorials. A greater fraction of the time seems to be spent on physics than at Aligarh and the total of formal teaching hours in the final year appears to be high (840 hours), and perhaps for these reasons there appears to be more, and more sophisticated, physics in the course. The course is designed for training the professional physicist.

Full data on the employment of first degree graduates in India have not been obtained. A 1971 census reported that six months after graduation about 25 per cent of science graduates were unemployed, in temporary employment or not available for employment. About 20 per cent of graduates go into teacher training and the rest are divided between higher degree courses and direct employment. In the latter category (again according to a 1971 census), for first degree courses as a whole 27 per cent are in schools, about 4 per cent in colleges and polytechnics, 49 per cent in government and public sector work, 12 per cent in private industry and about 8 per cent in other private organizations. There is currently a debate in the country about the relevance of the curricula to national needs, and it is being argued that courses which are job orientated and relevant to social conditions must be introduced. The overall pattern of school curricula varies from one state to another but is being changed in many states to a pattern in which after ten years in school, students will have a higher and more specialized level of attainment in their university course subjects. This will lead to a substantial up-grading of university courses, and new plans for these are being considered. A proposed course for one university (Nagpur) is a course lasting two years for a pass degree with a third honours year and is almost entirely a pure physics course based on the main conceptual themes of physics.

Table 9
Curriculum at Jamia Millia, Islamia, India
Numbers in brackets are approximate total hours per course

Year 1		
Laboratory	(200)	Mechanics (30), P. of M.[1] (30), Hydrodynamics (10), Thermal Physics (55), Wave Motion (25), Optical Instruments (20), Magnetism (20), Electrical Circuits and Measurement (65) Together with Mathematics and Chemistry
Year 2		
Laboratory	(200)	Thermodynamics (65), Physical Optics (65), E.M. Theory[2] (35), E. and M. Fields[2] (85) Together with Mathematics and Chemistry
Year 3		
Maths. for Phys.	(120)	Atomic and Molecular P. (60), S.S.P.[5] (60)
Lab. with Project	(360)	A.C. Circuits (40), Q.M.[3] (60), Electronics (60) N.P.[4] (60), Relativity (20)

Typical Textbooks
[1] Halliday and Resnick;
[2] Marian, Classical E.M.;
[3] Dicke and Wittke, Schiff;
[4] Kaplan, Cohen;
[5] Kittel.

2.2.7 The University Course in Rabat, Morocco

Students enter at age 19 after a general school education in which physics will have been studied as one of six or more subjects. The course lasts four years, in the first two of which there is a common course concentrating on mathematics and physics and (rather less) chemistry. Students then choose either physics or chemistry for the last two years. Details are given in Table 10.

The main problems reported are those of obtaining a more logical cohesion in relating physics topics to another and in relating mathematics teaching to the needs of physicists. Of those taking a first degree, 75 per cent enter secondary school teaching, 10 per cent enter for M.Sc. or Ph.D. work, and 5 per cent enter teacher training courses.

2.2.8 The University of Paris

Students enter at age 18, having in their last year at school, spent about 5 of the 30 hours of teaching on physics and chemistry and about 9 hours on mathematics. The degree course outlined in Table 11 extends over four years, the first two years leading to a national diploma which is a prerequisite for the second cycle, a further two years leading to the '*maitrise de physique*'. This latter is also a national diploma, and the general structure of the curriculum is nationally determined although each institution is free to arrange its teaching within this framework. Laboratory work is, in principle, included within each course, as is problem class work. The course is designed mainly for professional physicists. There are difficulties in relating with the

Table 10
Curriculum at the Université Mohammed V. Rabat, Morocco
Numbers in brackets are hours of teaching

Year 1		
Mathematics	(125)	Mechanics and Optics (75)
Laboratory	(40)	Atomic Physics (includes chemistry) (30)
Year 2		
Mathematics	(125)	E.M. Theory (75), Thermal Physics (50)
Laboratory	(70)	
Year 3		
Mathematics	(75)	Q.P. and A.P. (80), Mechanics (50)
Laboratory	(70)	Relativity-Radiation Theory (50)
+ Lab. on some options		*Choice from* N.P. (70), Electronics (70) or Theory (70)
Year 4		
Laboratory	(70)	Statistical Physics and Thermodynamics (80)
		Optics-Molecular P. (80)
		Choice from Same options as for Year 3.

Theory option Years 3 or 4 includes S.S.P., Elementary Particles and Relativistic Quantum Theory.

required mathematics. Other problems arise because of the wide range of options available: for example, students can enter the second cycle having followed quite different courses in the first. This optional character of the courses is one of the main differences from previous reports of courses in France. Data on these are to be found in the 1966 Unesco report and in the 1967 report by Hanle and Scharmann [12].

The majority of students (about 70 per cent) carry on to work for a higher degree. Industrial employers prefer to employ graduates from the 'Grandes Ecoles', the institutions in which engineers are trained. This institutional separation may have the effect of enhancing the emphasis on pure physics in the degree curriculum. Detailed data on employment of graduate physicists have not been obtained.

2.2.9 University Courses in Italy

Students who enter the university, usually at age 18, have studied physics in school for about three hours per week, generally in only their last two or three years at school. The four year course has the same general structure (established by law) throughout the country, and allows for three types of physics degree: in general physics, in applied physics and in physics for teaching. The curricula for the first two are identical until the fourth year; the course for teachers differs in the last two years and is not discussed here. The curriculum is presented in Table 12; the details are for the courses in the University of Bologna. For each course, there are numerical exercises of about 40 hours per course.

The courses are designed for training professional physicists. Students may, by special arrangement, vary their course to concentrate on related fields (e.g. biophysics). The main

Table 11
Curriculum at the University of Paris

Numbers in brackets are hours of teaching

Year 1		
Mathematics	(200)	Mechanics (100), Electricity (50) Structure of matter (50), Data Processing (50) In addition an option chosen from any field of study from physics to Chinese
Year 2		
Mathematics	(100)	Q.P. and Thermodynamics (100) or Relativity and E.M. (100). Science option (e.g. mathematics, electronics, chemistry) (100), Foreign language (100), Non-science course (100)
Year 3		
Mathematics	(50)	Thermodynamics, Structure of Matter (200), Oscillation, Waves, E.M.,[1] Optics (200)
Year 4		
Mathematics	(50)	Q.M.[2/3] (100), Atomic Physics (50), N.P. (50), Physics Options (200)

Typical Textbooks

[1] Berkeley Vol. 3.; Waves
[2] Messiah,
[3] Feynman Vol. 3.

problems under discussion in Bologna are the need to coordinate courses and avoid repetitions and gaps. Students and some teachers are also concerned to discuss social implications of the work of physicists. The specializations do not predetermine employment – a graduate in the 'physics for teaching' course is not necessarily preferred for a teaching post over a graduate in one of the other two courses.

A detailed survey of the employment of physics graduates in Italy was published by Focardi and Tomasini Grimellini in 1973 [10] and reports data and opinions collected in 1971 from those who graduated in physics in Italy in the years 1966–70. The numbers of physics graduates rose steadily in this period from 624 in 1967 to 912 in 1970, and responses were obtained from about 80 per cent. Of these, 29 per cent were in schools, 12 per cent in universities, 13 per cent in research institutes, 18 per cent in industry, 7 per cent in other work and 22 per cent unemployed. 13 per cent of the sample had taken the 'physics with teaching' degree and 45 per cent of these were teaching whereas 53 per cent had taken applied physics and of these 22 per cent were teaching, 24 per cent in industry and 14 per cent in research institutes. The types of industry with large proportions of the total of employed graduates were computing (31 per cent), electronics (24 per cent), mechanical engineering (14 per cent), and chemical (8 per cent). Graduates in industry were mainly employed in technical (55 per cent), research (34 per cent), commercial (6 per cent), or administrative (1 per cent) work. Satisfaction with work was highest for these in industry, commerce or universities and lowest for those in schools – the main reason for dissatisfaction being economic. Thirty per cent were little satisfied or not satisfied with their

Table 12

Curriculum in the University of Bologna, Italy

Numbers in brackets are total numbers of hours for each course

Year 1	Mathematics (120) Laboratory (90) (50% Formal, 30% Projects, 20% Computing)	General Physics I $^{1/2}$ (Mechanics, Thermodynamics) (60) Chemistry for physicists (with laboratory (60)
Year 2	Mathematics (50) Laboratory (90) (Optics, Electricity)	Mechanics (60), General Physics II$^{1/2}$ (Optics and E.M.) (90) (Competence in two foreign languages required)
Year 3	Mathematics for Physics (60) Laboratory I (90) (Electronics, Circuits, Computers)	Structure of Matter$^{6/7}$ (60) Theoretical Physics I$^{3/4}$ (60) One optional course (60) (N.P., S.S.P., Relativity, Statistical Mechanics, Astrophysics, Epistemology and Methodology)
Year 4	Laboratory II (S.S.P. Elem. Particles Data Analysis)	Elementary particles, Quantum electrodynamics (60), Quantum Theory of radiation and fields (60) and one optional course (see above) or 3 optional courses (from lists in nuclear physics, physics of matter electrotechnics, astrophysics, geophysics)

Typical Textbooks

^{1} Feynman Vol. 1,
^{2} Berkeley, Physics Course;
^{3} Messiah Q.M.
^{4} Goldstein Classical Mechanics;
^{5} Dirac Q.M.;
^{6} Born Atomic Physics;
^{7} Coulson Valence.

work, whilst 26 per cent said that in the light of their experience they wished they had taken a different degree: most of these named either engineering or medicine as courses they would have done better to take. A further enquiry for graduates in the years 1970–74 is due to be published.

2.2.10 Other Countries

Information about curricula in other countries can be obtained from the 1966 Unesco survey [20] (which also covers Czechoslovakia, Federal Republic of Germany, and U.S.S.R.) and from Hanle and Scharmann [12] (covering all Western European countries and Turkey). A more recent and detailed account of a course in the U.S.S.R. has been published in English by Artsimovitch [5] and is of interest because it describes a course which takes longer (5½ years) and involves more timetabled teaching (35 periods of instruction each of 45 minutes per week, giving over 1 000 periods in each of the first three years) than any of the other courses surveyed here.

2.3 GENERAL CONCLUSIONS

2.3.1 The survey data

Differences in terminology and in methods of classifying teaching activities and teaching time mean that it is hard to translate information from many countries into the common format that is needed for valid comparisons to be possible. Hence any conclusions drawn from the data in Section 2.2 must be tentative. Any degree curriculum is partly determined by the constraints within which it is constructed: these again are diverse. Some are mentioned in the survey, for example, the educational standards of students on entry, the university rules about the proportion of time to be spent on specialist subjects and national control of curriculum. Others, such as financial and staff resources have not been discussed.

Even with these reservations it is clear that there are wide divergences between different systems. For example, if a total year's teaching time is reckoned as 1 unit, then the number of units of physics and mathematics in a first degree course can vary from under 2.5 to over 3.5 even in courses which are all nominally four year courses for a degree in physics. If numbers of hours assigned to physics lecture courses are reckoned, then the total can range from 500 to 1200, whilst the time nominally devoted to mathematics can vary from about 100 hours to 400 (in the courses displayed in tables) and even to over 900 (in the Moscow State University). Other important variables are more difficult to infer from the data, but it is clear that the proportion of course time devoted to tutorial or problems work can vary (40 per cent in the early years in M.I.T. to under 20 per cent in several courses) as can the total time devoted to laboratory work (from around 300 hours to over 700 hours). Before making even the most tentative judgements on courses it would be essential to know more about the teaching/learning styles (the same hour of activity can be classed as lecture in one system and as tutorial in another) and about the range and extent of independent learning work by students, which is arguably the most important piece of missing evidence. Finally, it would be interesting to relate this range of course inputs to the achievements of the students: this would require the collection of data on assessment standards, which would be very hard where thesis and oral work is extensively used.

However, a few simple uses of the data can be suggested. We can each compare our own courses and check whether they are untypical in any important respects: if they are it can be asked how the peculiar features are justified, or whether the teaching resources might be re-distributed. A second use might be to suggest a uniform code for describing the characteristics of courses in a brief form: for example, such a coded description might read as follows – Four year, 2.5 physics + mathematics, 300 hours mathematics, little free time, 300 hours laboratory all structured, low tutorial ratio, few options. A third use might be to serve as a starting point for collection of better data, for example, it might be asked whether it would be helpful to have comparative data on aspects not reported above or more precise data on those reported imperfectly.

2.3.2 Articulation of Courses

It comes as no surprise that most of those who kindly sent reports on courses to the author referred to the difficulty of relating the mathematics to the physics teaching. However, many also referred to concern about relating physics courses to one another. An overall coherence and unity in a physics course ought to be perceived by the learner, both because it helps the learning of particulars to see them in a general framework and because anyone who has not perceived the intricate yet elegant conceptual structure whereby physics is unified will not understand and will never fall in love with the subject.

One aspect of the difficulty is the diverse characteristics of component courses – some serve practical needs of technique (electronics), some are concerned with fields of application which draw on many theoretical principles (atmospheric, solid state, or nuclear physics) some are concerned with a unifying theoretical principle but could include many fields of application (quantum theory, wave motion). The optimum selection between these various ways of dissecting physics would ideally be determined by a debate to reconcile the fundamental structure of the subject with the fundamentals of a theory of learning: there are few signs that this debate has even seriously begun.

The common pattern of courses – first year(s) general survey, middle year(s) tough theory, last year(s) fields of application – may be optimum, but it is clearly as much a function of institutional constraints as of learning needs; it is administratively easy to let one teacher dispose of quantum mechanics first and then at a later stage let others separately teach the topics which 'need' this and other theories, but by what model of learning is this justified?

The perception of unity between material learned in different contexts and the transfer of learning that this requires are far more difficult for the novice than most experts imagine; this might be a reason for preferring courses based on unifying themes, but if these are theoretical and interpreted in a sophisticated way the effort may be counter-productive. One solution is to connect courses in designed sequences (e.g. to treat wave-motion, electromagnetic theory, physical optics as a linked sequence) rather than present them as isolated entities. Such articulation demands very close cooperation, in both planning of courses and their presentation, between those actually doing the teaching, so that both the general aims and the details (e.g. common notation) are shared by the teachers. It is of interest that, where a curriculum emphasizes linked sequences, the department (in Ohio State University) also lists the teams of staff responsible for each sequence. The Open University in the U.K. has designed its courses as team efforts (see the article by Kay and Pentz [16]) and many with previous experience of conventional university systems are convinced of the need for cooperative work. Exposure of one's plans and performance in close and frequent interchange with colleagues is essential to achieving a high critical level of work and is taken for granted in physics research. Cooperation undertaken to help learners see the components in relation to the whole should also improve the quality of the components.

It is obvious that any ideal articulation must be reconciled with many constraints, e.g. the need to have a general survey in a first year because the course also serves non-specialists. One important issue here is the constraint imposed in any system which permits a wide range of options.

If an optimum learning system for physics requires a close coordination of individual courses or the linking of sequences of work into long courses, then it will be more difficult to secure these conditions as the range of options is increased and the size of option units is decreased. However, the ability to select options does mean that a student is more likely to feel that his course is his own and suits his needs, and if this enhances his ambition to do well it may offset the less satisfactory learning pattern of a unitized system. The reconciliation of choice with structure takes a spectrum of forms from the very free variety of unit courses (at Chelsea College, London) through the courses which present various forms of core with substantial options (Ohio State, U.S.A., Birmingham, U.K., Bologna, Italy) to courses permitting only a single route. It would be valuable to debate the balance of advantage in this spectrum of possibilities.

2.3.3 Employment

There are sharp contrasts to be discerned in the relationships of physics curricula to the employment prospects of graduates. In some countries a pure physics course designed for training professional research workers may be justified directly by the high proportion of graduates proceeding to further degree work in physics. In others, such as the West Indies, there is recognition, in both research and teaching programmes, of the need to relate the training of physicists to the types of applied physics which may contribute to problems of the country. Some systems have broad options to allow an applied bias within professional training but both in these cases (e.g. Italy) and in universities which provide only pure physics courses (e.g. some U.K. courses) it appears that graduates from pure physics courses can enter a wide variety of employments. Finally there are examples where the mismatch between the accepted value of a physics training and the employment opportunities is creating or seems likely to create serious problems.

In many countries, a growth during the sixties in higher education and in pure research may have produced expectations which cannot be satisfied and a distribution of resources and talents which is no longer viable because the growth has been replaced by decline. In such situations, three alternative solutions may be explored. The first, to reduce numbers to match the current pattern of demand, does not need discussion, in that it is justified if the other alternatives fail. The second is to convince graduates and employers that trained physicists are well equipped for a wider range of careers than they have entered in the past. This position is justified by emphasising the merits – quantitative thinking, abstract thought, test through experimentation – of the intellectual disciplines of physics, and this argument has enough validity to be very attractive to the pure physicist seeking to justify the teaching activity for which he feels best equipped. But a critical appraisal is needed – for similar arguments were used to justify education in Latin and Greek (which were less costly to teach). It may be asked whether the transfer of the physics training to non-physics problems will occur, and whether courses in which the same intellectual powers could be developed on material directly relevant to subsequent work might have a better chance of success. Justification of the physics curriculum in this way may be possible only if that curriculum satisfies certain characteristics. For example, the personal qualities, attitudes and skills that a course develops are far more important than the completion of any particular piece(s) of physics content (see the article by Buley in Jevons and Turner [13]), and a measure of success and enjoyment for the average or below-average graduate from the course may be essential if he is to have any desire to deploy, in a quite new field, the skills learnt in studying physics.

Such arguments lead naturally to the third solution, which is to adapt courses to match employment needs. Different types of adaptation are possible. One is to direct attention to topics in physics of direct relevance to industrial and social problems. Another is to emphasize skills and attitudes in the manner outlined above, which might, for example, lead to greater emphasis on task-oriented work and on communication skills. A third type or aspect of adaptation is to broaden the studies beyond physics, for example through inter-disciplinary work on problems or by inclusion of elements of study in other disciplines, such as social sciences and economics, to give a broader preparation for work outside pure research.

Changes such as these encounter two obstacles. One is that they force physicists to reconsider the definitions and boundaries of their subject. They may require physics to be developed as a closer neighbour to the various fields of engineering, biology and earth sciences, and institutions in which close cooperation and overlap between physics and other courses is easily arranged will be able to adapt more readily in this way. The second obstacle is that some of the required adaptation may be in deep conflict with the natural tendency of the university physicist to concentrate on soluble and well defined problems and to remain enclosed within those narrow confines where he has confidence in his own expertise. These tendencies have been elegantly analysed in an article by Weinberg [23] who suggests that the 'task orientation' that could correct the dangers of academic specialization is to be found, not in modifying academic research as such, but in commitment to the task of education of students which has the characteristics of an 'engineering' problem rather than of a problem in pure science. A different line of argument which bears on the same problem has been exposed by Pippard [19] who warns that the sophisticated abstractions of physics theory may be less useful to many graduates than simpler formalisms, which can encourage physical intuition in guessing solutions to intractable problems. Courses should give more emphasis to the value of experiment and semi-quantitative thinking in coping with a wide range of real problems. However, he goes on to conclude that such a shift could produce an education in which there could be natural stopping points, matched to the career needs of many graduates, well before the stage of theoretical sophistication reached by many first degree courses and that, in the U.K. context, this should lead to shorter first-degree courses. A detailed discussion of various aspects of the relations between science degree courses and employment needs, written in the context of the U.K. situation, is given in a collection of essays edited by Jevons and Turner [13].

2.3.4 Illusion and Reality

The arguments in Section 2.3.3 show that it is necessary to re-appraise the aims of degree courses. If the aims were altered then the content and the style of teaching would also need to be re-considered. However, there is another quite different reason for thinking again about the degree curriculum.

There is evidence that students studying sophisticated physics often have a poor understanding of basic concepts. In the U.K., Fremlin and Durrani [11] report their experience of interviewing recent graduates for entry to M.Sc. courses: those graduates often make gross errors in the simple qualitative descriptions of processes and topics for which their course had included detailed study. They argue the need for substantial reduction in the content of first degree courses. In France, Viennot [21] posed questions testing understanding of the basic concepts of Newtonian mechanics to university physics students in their first and third years: the results were uniformly poor, the only difference between the two groups being that first year students justified their errors with qualitative arguments whereas third year students used formal and mathematical language to justify the same mistakes. Similar evidence comes from the experience of introducing Keller plan courses: it is usually found that the content of courses, for which students have to show evidence of mastery of the basic concepts as they proceed, has to be at least 20 per cent less than that previously covered when the same course was delivered in lectures.

This evidence is supported by the informal opinion of many physicists that students studying sophisticated physics often have a poor understanding of basic concepts and can achieve only a formal knowledge of their work, so that they can memorise it and solve routine problems but lack confidence in discussing it and cannot translate and adapt it for any novel situation. It is important to discuss whether this opinion is generally held, how the situation could have arisen and what changes might need to be made.

One important feature is the difficulty of communication between teachers and learners during a course; where tutorial methods enable teachers to see clearly the progress and understanding of which the average student is really capable, they are usually surprised and discouraged – but only a few take the next step and adjust their courses. Thus there is a need to encourage methods which improve this communication. Evidence provided by assessment at the end of courses seems to be ineffective, perhaps because it is forgotten by the time the course is repeated, perhaps because it is too readily discounted by allowing for examination conditions, often because rote learning enables many students to pass even if they have not really mastered the subject.

The problem might arise because the difficulty of being objective about the achievements of students is compounded by the ease of judging the status of a course from its list of contents. The natural tendency of the able research physicist to over-estimate the learning capacities of his students is supported both by the desire of individuals and institutions to maintain appearances, and by their pride in the sophistication of their subject. Who would be brave enough to offer a course reduced far below the local or national norm and to defend his action by claiming that his students were going to learn and understand more physics because of the change? (The students might instead devote more of their time to other courses and so do better in them.) Individual teachers, and individual institutions which do not have the highest prestige, may find it impossible to respond on their own to this problem without grave risk to their reputations.

It would be wrong to assess this problem simply as one of reducing content. Pippard has emphasized that courses should concentrate more on broader applications and implications of simpler ideas. Other evidence from tutorial sessions devoted to development of specific skills (Black, Griffith and Powell [8]) has shown the need to devote more explicit attention to the skills involved in scientific thinking. The introduction of project work into laboratory teaching may be justified because project tasks are analogous to the real tasks of an experimental scientist and so automatically enhance skills and attitudes which may have been neglected in a 'teaching' activity which is related to future needs by way of a model of 'preparation'. It is in fact the adequacy of the models of 'preparation' or 'training' whereby we justify the selection of content and activities in our courses, which is being called into question. Reduction in content is not an end in itself, and the ends, for which such reduction may be the essential means, need to be carefully explored.

2.4 THE GROUP DISCUSSION

2.4.1 Difficulties Facing University Physics Courses

In certain countries, the number of students entering physics programmes has fallen seriously below the number of places available. Even where this is not the case, the general impression of physicists is that the quality of the students studying physics has fallen in the past few years. Good students who might formerly have studied physics appear to be more attracted to fields such as medicine, engineering and mathematics.

Although changes are being made in university teaching, particularly in the content of courses, the effect is relatively small and much less well known compared to the reforms of curricula and teaching in schools. This may make the transition from school to university more difficult and so exacerbate the basic problem, that physics as currently taught in universities is more difficult than other subjects.

The impression of difficulty is one aspect of a generally unattractive image of physics that young people have acquired. Physics does not appear to deal with real things which can be seen and handled, but rather with abstract entities which are to be 'learnt about'. Because many of their teachers present physics dogma rather than encouraging involvement in physics as an activity, teenage students feel that they cannot contribute their own ideas on this subject, at a time when they increasingly expect their views to be heard and considered. A study of young people's views (Ahlgren and Walberg [1]) shows that, by comparison with other subjects, physics ranks highly in 'maturity and importance' but very low in 'friendliness'. Physicists appear to be impersonal, even inhuman.

Another aspect is the repulsion that many feel at the dominance of society by technology, linked to the evils of war, energy wastage, and pollution. Thus the remote abstraction of *pure* physics is complemented by the unpleasant effects for which *applied* physics is held responsible. When this disaffection is combined with uncertainty about job opportunities, then all the important influences on a young person, including peers, parents and the media, tend to discourage him from committing himself to physics.

Many degree curricula demand too big a commitment. A physics curriculum is often a lengthy and rigid sequence of courses, finding logical completion only in the post-graduate studies which it is designed to serve. There is no provision for those who do not have the interest or ability for such a complete and narrow devotion. The range of alternatives could be so much wider than the two that usually exist – all or nothing.

The final source of difficulty lies in ourselves, the university physicists. We have been formed as physicists in the tradition that is responsible for many of the problems mentioned above. We cannot easily change, yet without a change in our own attitudes and outlook, other reforms can bear little fruit.

2.4.2 Making Physics More Attractive

We must convince society that physicists can serve its needs. This is a large and diverse task involving, for example, serious attempts to relate physics to the problems that citizens meet in their work and in their homes and to the interests of children. More physicists should devote their efforts to such work. Its value, to physics and to the whole community, ought to be recognised.

One important aspect of any attempt to change the image of physics is the need to emphasize that it is an activity of people. One way in which this has been done for students is to offer a non-examinable course of talks given by physicists about their personal interests. Another way is to give more time to personal and historical stories to supplement the formal presentation of physics. Above all, we must in teaching give a personal view rather than deliver a computerized message. Many school-teachers do not inspire their pupils because they were never inspired themselves: thus the defects of university teaching are handed down to the school classroom.

It is not possible to make useful changes unless time is devoted to the task. This may mean that there is less time to "cover the curriculum".

Courses should also show the unity of physics, which again takes time and requires detailed and continuous attention. Students find it hard to see links between topics – they are only likely to do so if they have confidence in their understanding of the topics which are being linked. In general, confidence is too often lacking in undergraduate studies, but no student will struggle for long unless he gains some of the rewards, of wonder, delight, and intellectual satisfaction, which such struggles deserve.

Since doubts about employment are a frequent and valid reason for avoiding physics, physicists must be prepared to study employment needs and to design their curricula to meet them. The implications of this are discussed in Section 2.4.4.

The comments in Section 2.4.1 to the effect that we physicists are both victims and agents of the problems, have their counterpart here. A change of emphasis in teaching requires changes in teachers. For some purposes, institutions may need to look for physicists with more diverse interests and experience.

2.4.3 The Goals of the Curriculum

The goals of the curriculum ought to relate to employment opportunities but should not necessarily be matched in a narrow way to the needs of particular occupations. The earlier part of this chapter implies that the commonly accepted goal, of training professional physicists for further work in a graduate school, might no longer be justified as a primary objective. There was emphatic agreement on this point. Moreover, it was argued that even students going on to postgraduate academic research would be better served by a broad physics education rather than by one narrowly designed for pure research.

A second possible goal for a degree curriculum is that of providing a general education through physics. This has the implication for employment that both graduates and prospective employers consider physicists to be well equipped for a wide range of careers. This possibility has been discussed earlier in the chapter and apart from the example quoted in 2.4.4 below (the Stony Brook course) it is not further developed here.

However, the third, possible goal requires much more emphasis. This goal is one of training physicists who are prepared to use their physics in a wide range of practical applications. Physics is the basic science for most scientific and engineering activities and we must emphasize and exploit this. This goal is relevant everywhere but has additional force in the developing countries. Although many of their industries call for specialized engineering graduates, it is not sufficiently recognised that an economy which requires development of simple technology may best be served by an 'engineer' with a broad grasp of fundamental principles – that is, by a physicist. However, to produce such a graduate, curricula must change, and it may only be possible to justify the survival of physics programmes if such changes are made. A physics degree can then become, and be accepted as, a preparation for a wide range of careers. It could well be that such a curriculum, which combines adequate study of physical principles with emphasis on a range of applications, is also the optimum way of meeting the second goal – general education through physics – mentioned above.

2.4.4 Changing Courses to Meet new Goals

Several types of curricula can provide ways of emphasizing the use of physics for a range of industrial and social needs. One way is to have a basic curriculum for the first two or three years followed by a final year containing options in both pure and applied topics. Another is to provide interdisciplinary curricula – a solution which is being explored in many countries and which is very relevant to the problems discussed here (although it was excluded from the survey in Section 2.2).

A third type of solution is to construct a curriculum devoted exclusively to Applied Physics. One example of such a curriculum, from the South Australian Institute of Technology, was discussed. Its structure and content are moderated by a group which includes representatives of industry and government. Topics such as electronics, electrical engineering, metallurgy (all taught by appropriate specialist departments) and options in such applied areas as X-rays, solid state devices and health physics, occupy a substantial fraction of a programme. It nevertheless starts with substantial courses in basic mathematics and physics. The study of topics such as quantum mechanics is limited to aspects directly relevant to applied physics. The practical work includes a project in the final year which is frequently undertaken in industry, hospital or government laboratories. The programme is taken by both full-time students and by part-time students in other employment. It produces graduates suited mainly to the needs of industry but also to the needs of secondary school and technical college teaching. Similar programmes involving more extended periods of work in industry, have been developed as 'sandwich' courses in the United Kingdom and other countries (Bates [7]).

A fourth, and rather different approach is the General Degree Programme at Stony Brook

(New York, U.S.A. – see Kahn and Strassenburg [15]). This was planned as an alternative to the existing programme (designed for graduate school or industry) with course topics emphasizing the historical and social side of physics. The choice and sequence of the component courses is flexible and in each course emphasis is placed on student's reading and reporting on books by and about the physicists whose work is being studied. The enrolment in this programme is as large as in the research oriented programme. A significant feature is that many of the students aiming for research careers now select some of their courses from this General Degree Programme.

These changes in curriculum structure re-open the issues about articulation of courses discussed in section 2.3.2. It is clear that most physics curricula have a central core of 'basic' physics, sometimes, according to the school system of the country, following a variety of introductory first-year courses, and usually followed by courses which branch out into many areas of application. One response to social and industrial needs is to provide more of these branches. The difficulties here are the strain on resources involved in providing many different branches and the relegation of all applied branches to second class status, often because the core material has been presented with an implicit and powerful message that 'pure' physics is the only respectable physics. The core itself is the source of many of the difficulties discussed in Section 2.4.1. As mentioned in Section 2.3.2 the necessity for it derives from a view of physics rather than from views about the way students learn. Because it can deter and depress students, it is important to explore possible modifications and alternatives. One is to teach some of the topics at two different levels, another is to allow students to spend longer over the topics or to defer some to a later semester or year if they wish. Another is to allow students to delete some of the topics entirely and accept a more limited range of subsequent applications – which they can explore at more leisure because the selection leaves more time. The development of these possibilities into a programme of flexible yet coherent alternatives is a difficult problem in curriculum engineering, which cannot simply be solved by providing students with complete freedom to wander through a forest of options.

It has always been believed that advanced teaching in physics must be given by those actively involved in research, and it may follow that only those who are themselves engaged in using physics for applied problems can do full justice to this aspect in their teaching. It is clear that if graduates are to be willing and confident in applying themselves to tackling applied problems, they should have experience of such work through undergraduate projects; thus, these projects may be essential for the goal discussed here. Furthermore if the teacher who guides the student does not himself know the 'solution' then he may communicate better the response of a physicist to such problems.

All of the changes considered above are changes within the present framework of universities and their degree programmes. However, in the future we may have to consider how physics programmes might fit into quite different frameworks. In some countries serious attention is already being given to more open and flexible arrangements which permit students to leave courses and re-enter later in their careers.

2.4.5 Illusion and Reality

The message here, that we put too much material in our courses and then hide from ourselves the students' failure to do more than learn it by heart, was endorsed by the group. The quality of the experience and of the achievement of physics students can only be enhanced if physicists are prepared to make substantial reductions in curriculum content. Such reduction will not lead to a lowering of standards – it is a necessary condition for raising the standards of understanding. What we must stop doing is to force all students to follow a path which only the best manage with any comfort.

2.4.6 People

All of the above sections state or imply a need to change our own attitudes. The fundamental reason for this is that the most effective teaching involves a personal interaction between the learner and the teacher. If, and only if, we accept a wider sense of responsibility to the rest of society and a deeper concern for personal values, shall we be able to convince students that physics is an activity worthy of responsible human beings. This implies that some physicists will have to broaden the scope of their work and interests in physics, whilst those who rightly remain committed to pure research should respect and encourage this wider contribution.

2.5 BIBLIOGRAPHY

1. Ahlgren A. and Walbérg, H.J. Changing Attitudes towards Science among Adolescents. *Nature* vol. 245, Sept. 1973, p. 187–8.
2. American Institute of Physics. The Undergraduate Curriculum *Physics Today,* vol. 21, no. 3. March 1968, p. 23–65.
3. American Institute of Physics. *Enrolments and Degrees* pub. no. R-151.11. May 1974.
4. American Institute of Physics. *1973-4 Survey of Physics Bachelor's Degree Recipients.* pub. no. R-211.6. February 1975.
5. Artsimovitch L. Studying Physics at Moscow State University. *Physics Today* vol. 23, no. 1. January 1970, p. 34–40.
6. Australian Department of Labour. Physicists. *The Australian Physicist.* vol. 10, no. 12. December 1973, p. 191–4.
7. Bates, C.A. Physics degree courses. *Physics Education,* 8 no. 3, May 1973, p. 135–141.
8. Black, P.J., Griffith, J.A. and Powell, W.B. Skill sessions. *Physics Education,* vol. 9, no. 1, January 1974, p. 18–22.
9. Ebison, M.G. Data on Careers for 1973 Graduates in Physics. *Physics Bulletin,* vol. 25, July 1974. p. 281–2.
10. Focardi, S. and Tomasini Grimellini, N. Survey of Physics Graduates for the four years 1966–70. *Giornale de Fisica,* vol. XIV, no. 4. Octobre-Dicembre 1973, p. 312–406 (In Italian).
11. Fremlin, J.H. and Durrani, S.A. Degree Standards. *Physics Bulletin,* vol. 25, March 1974, p. 87–8.
12. Hanle, W. and Scharmann, A. *The Teaching of Physics at University Level.* Council for Cultural Co-operation of the Council of Europe. Strasbourg 1967.
13. Jevons, F.R. and Turner, H.D. *What Kinds of Graduates do we Need?* Oxford University Press 1972.
14. Jones, G.O. Physics in the new London B.Sc. degree. *Physics Education,* vol. 4, no. 3. May 1969, p. 143–150.
15. Kahn, P.B. and Strassenburg, A.A. Instructional Innovations in Physics at Stony Brook. *American Journal of Physics,* vol. 43, no. 5. May 1975, p. 400–407.
16. Kay, A.R. and Pentz, M.J. Integrated Multi-media Systems in *New Trends in the Utilization of Educational Technology for Science Education.* UNESCO 1974, p. 143–176.
17. Kothari, L.S. Present Status of Physics Education in India (College and University Level). *Survey of Literature on Physics Education.* Produced for Edinburgh International Conference 1975.
18. de Laeter, J.R. Student Statistics in Physics in the Colleges of Advanced Education. *The Australian Physicist,* vol. 11, Oct. 1974, p. 200–201.
19. Pippard, A.B. The Educated Scientist. *Physics Bulletin,* vol. 20, November 1969, p. 453–9.
20. U.N.E.S.C.O. *A Survey of the Teaching of Physics at Universities,* Paris 1966. 396p. tables.

21. Viennot, L. Physical Understanding and Formal Reasoning in Elementary Dynamics. *Bulletin de la Societe Francaise de Physique.* Encart Pedagogique vol. 11. Supplement au Bulletin no. 16, Mars 1974. p. 35–46. (In French).

22. Watson-Munro, C.N. Numbers of Physics Students. *The Australian Physicist,* vol. 11, no. 3, March 1974, p. 33–4.

23. Weinberg, A.M. But is the Teacher also a Citizen? in *Science and the University.* Columbia University Press 1966, p. 162–178.

3 New approaches to teaching and learning in universities

This chapter, based on a paper written by M.A. Moreira, is primarily concerned with new teaching methods in which lectures are replaced by other activities such as small group seminars and individualized systems of instruction which are not heavily dependent on hardware. The Keller Plan or Personalized System of Instruction (P.S.I.), the audio-tutorial approach to learning, modular instruction and small group instruction approaches are described. In the light of these approaches, independent study, mastery learning, criterion referenced evaluation, team teaching and other current ideas are then discussed.

3.1 BRIEF DESCRIPTION OF SOME INNOVATIONS

This section describes some of the innovations increasingly used in the last decade. It should be explained at the outset that in spite of the fact that the new approaches tend to de-emphasise the use of lectures it is not the purpose of this chapter to deny the value of this type of instruction. There is no intention of suggesting that one method is necessarily better than another nor that the traditional systems of instruction should be replaced by the new ones. The use of one or another system or a combination of them is dependent upon existing conditions and resources, cultural aspects, objectives, etc.

3.1.1 Small Group Instruction

Small group techniques de-emphasise lecturing on behalf of a greater degree of student participation during the classroom period. Different terminologies like 'small group seminar', 'small group tutorial', or 'small group guided study' can be found in the literature. The basic idea, however, is that the class is divided into small groups and the students play an active role in the instructional situation. The size of groups ranges from 4 to 8 students.

Falk and Wall [7] described one of these techniques where all members of each group were prepared to lecture on a given topic. By having each group present its topic to the other groups, some involvement of each student with almost all the material was maintained throughout the semester. Meetings between the teacher and individual groups were used to keep general control over the course, to make sure that the key points were not missed, to help students in more difficult sections and so on.

In another report, Moreira and Costa [16] described the following technique: at the beginning of each class, after a brief introduction, the students received a handout containing questions and problems to be solved in small groups. A report of each group's work was due at the end of the class lasting two hours. During the class the teacher circulated among the groups guiding their work and providing assistance when necessary.

Munsee [17] reported a similar technique: the students were randomly placed in small groups and a group project was assigned. The students had much freedom to decide on a pace at which to cover the material of the course as well as on the project. Again the teacher circulated among the groups, helping when needed.

Black, Griffith and Powell [3] described a small group teaching method (skill sessions) designed to help students in acquiring some of the specific skills which are needed in the practice of physics. For example, a skill session may be concerned with estimating orders of magnitude. In a skill session a group of about 16 students meets a teacher for one hour. The teacher spends a few minutes explaining why the particular skill is useful to a physicist. The students are then divided into four working groups and each group is asked to choose one out of a set of four problems, to work as a group and to be ready to report their findings in about 30 minutes. During the next half hour the groups discuss their ideas. In the last few minutes the teacher might briefly sum up the discussions. This type of session is being tried in about six departments of physics in British universities at the moment.

In general the small group approaches are designed to replace lectures (but they do not necessarily exclude them or other large group activities), but they can also be used in a laboratory session. The evaluation of the students is usually based on the group activity as well as on individual homework assignments, quizzes and examinations. Course reports usually claim that the students enjoy the small group approaches, they learn as much as in the lecture method, they participate actively and feel a deeper involvement with the subject matter. It is also claimed that personal interaction is enhanced and a more informal student-teacher relationship is developed. It should be noted, however, that if small group instruction is the sole method of teaching there is a danger that the routine may become too stereotyped for the students.

3.1.2 The Personalized System of Instruction (PSI)

Also known as the Keller Plan, PSI is the most widespread new approach to teaching and learning in universities. It is an individualized approach based on the learning-reinforcement theory [14] with the following basic features:

(i) The go-at-your-own-pace feature, which permits a student to move through the course at a speed commensurate with his ability and other demands upon his time.

(ii) The unit-perfection requirement for advance, which lets the student go ahead to new material only after demonstrating mastery of that which preceded.

(iii) The use of lectures and demonstrations as vehicles of motivation, rather than sources of critical information.

(iv) The related stress upon the written word in teacher-student communication.

(v) The use of proctors (students selected for their mastery of course content), which permits repeated testing, immediate scoring, almost unavoidable tutoring, and a marked enhancement of the personal-social aspect of the educational process.

A great number of courses based on these five features have been designed during the last ten years. Examples of physics courses can be found in reports by Green [9], Anderson and Artman [1], Austin and Gilbert [2], Kahn and Strassenburg [12], and Moreira [15]. In general, course mechanics are as follows.

Course material is divided into units, and for each unit a study guide is prepared. It contains objectives, reading assignments, study questions and problems, references and introductory or explanatory materials if necessary. The student proceeds through the material at the rate, time and place he chooses. A proctor is available during class periods for individual assistance. The teacher is also available, but to a lesser extent because the ratio students/teacher is usually high as compared to the ratio students/proctor which is about 10.

When the student feels he has mastered the unit objectives, he requests and takes a test on the unit. The test is immediately evaluated by a proctor in the presence of the student.

Sometimes the evaluation is made by the teacher, but he usually acts indirectly providing answer sheets to the proctors and scheduling meetings to discuss the unit-tests with them. On the unit-test the student is required to show that he has mastered the objectives of the unit, i.e., he is required to answer correctly all items (some teachers require only 80 or 90 per cent). If the student passes the test he receives the study guide of the next unit and is encouraged to proceed. If he does not successfully complete the test, he is encouraged to restudy the unit and take another test on the same unit. No matter how many times a student is required to retake a unit, there is no penalty.

The way of assigning the final grades differs widely. One possibility is to give an A grade to all students who complete all the units and give other grades as a function of the number of completed units. Sometimes final exams are also used, but *usually* they do not have a discriminant weight in the final grade.

Some lectures are given during the course for students who have completed a certain number of units and are qualified to understand the material to be covered. However, attendance is not required and the lecture material is not included on the unit-tests. Laboratory work can be either part of a unit or an independent unit.

Answering end-of-course questionnaires, a great majority of the students say they have enjoyed the course, they would like to take another PSI course and they would recommend PSI courses to their friends. They also say they have worked harder and feel they 'have learned more'. Comparisons between PSI and lecture methods in terms of achievement in final exams and retention tests suggest that PSI is at least as effective as conventional approaches. The personal interaction among student, proctors and teachers is usually emphasized in PSI course reports.

3.1.3 The Audio-Tutorial Approach to Learning (AT)

Basically, in the AT system a wide variety of learning experiences is provided in an integrated form and the student's activity in these learning experiences is guided by audio-tapes. Originally the system included three major types of study sessions (Postlethwait, Novak and Murray) [21]:

(a) Independent study session (ISS). Weekly AT programmes are organized in a learning centre equipped with carrels for individual study. Each student can pace his study proceeding independently through the material to achieve the stated objectives for the week.

(b) General assembly session (GAS). Lectures, special films, major exams or other large group activities scheduled on a weekly basis.

(c) Integrated quiz session (IQS). A small group session, scheduled to meet weekly for one half-hour, involving eight students and an instructor. For this session each student is expected to prepare a little lecture about the material studied in the ISS.

At present the AT approach is closely identified with a learning centre where the student can work individually, stopping at any point in the programme to use additional resources such as supplemental texts and discussions with the instructor on duty or with peers. The basic equipment of a carrel is a tape recorder (which may be an inexpensive cassette type) with headphones, a slide projector and materials (laboratory equipment, for example) appropriate for the subject being studied. If possible, film-loop projectors should also be available. Even closed-circuit TV and computer terminals may be used in a sophisticated AT learning centre.

In spite of being developed independently, AT and PSI can be combined. For example, in the Physics Department of Cornell University [18] an AT approach entirely self-paced, using a mastery-based PSI type of evaluation is being used to run a large introductory physics course. Students study the units in a large learning centre where the materials of different units are available simultaneously. Videotaped lectures are available upon request from the students. Unit-tests are taken in a testing centre.

Evaluations of the AT approach also show a high degree of student satisfaction, an enhancement of personal interaction and an effectiveness, in terms of achievement, at least equal to the conventional approaches. The AT system can also be used (as well as PSI) in conjunction with mini-courses or modular units.

3.1.4 Modular Instruction (Modules)

A module may be defined simply as 'a self-contained and independent unit of instruction with a primary focus on a few well-defined objectives' [5]. 'Learning packages', 'instructional packages', 'audio-tutorial packages', 'mini-courses', 'conceptopaks' are some of the other names given to modules.

In general, the components of a typical module [5] are:

(a) *Statement of purpose (rationale):* description of the purpose of the package.

(b) *Desirable prerequisite skills:* if particular skills are needed before the beginning of a module, they should be stated explicitly.

(c) *Instructional objectives:* they describe what the learner should be able to do after completing the module.

(d) *Diagnostic pre-test:* to determine whether or not the student is prepared to undertake the module. Outstanding performance may indicate that the student need not take the module.

(e) *The modular programme:* learning activities and instructions so that the learner can independently complete the module. These activities may include writing, reading, listening, viewing, etc. Different learning activities to achieve the same objectives provide the learner with an opportunity to follow his own particular learning style.

(f) *Evaluation post-test:* to provide an index of the learner's accomplishments.

Modules may also include lists of equipment and supplies, self-evaluation tests, optional activities, teacher's guide, etc. Modular instruction is characterized by its flexibility. Modules can be used in a PSI or AT course or even in a more conventional course. They can be arranged in a variety of sequences to meet the individual needs of each student. Some modules can be studied at home. They also can be shared among institutions. Undoubtedly modules offer a wide range of instructional possibilities.

The United Kingdom's Open University [13] provides a good example of the use of modules. In this case the modules are designed to be used at home along with the textbook. They include an experimental kit, written materials, audio-tapes and self-assessment questions. Television and radio programmes are also integrated parts of the module. The purpose of the radio programmes is to create an atmosphere to motivate the students, but the television programmes are supposed to provide information. To be able to understand these programmes the student must study the module up to a specified point. After the television programme, the student works again on the materials of the module. The modules are sent to the students when they are due (it is not a mastery-based system). There is a degree of self-pacing, but the television programmes do not permit complete self-pacing.

The use of these new approaches or any combination of them is dependent, among other factors, on the objectives of the course. A good example is the approach described by Jafri, Ali and Ahmed [11]. A combination of lectures, small group discussions (both with and without the teacher) and individual work was used to provide the students with an opportunity to learn by themselves and for themselves, to work on divergent solutions for unstructured situations and to develop creativity.

3.1.5 Concentrated Study

Another example that may be mentioned is the so called 'concentrated study' [20]. In this approach, which basically consists of full-time study of a single subject for a short period (e.g. 4 weeks) with no concurrent academic commitments, a wide range of activities is programmed to achieve well defined objectives. It should be noted that a similar method obtains in Swedish University courses.

3.2 EMERGING PATTERNS

3.2.1 Individualized Instruction – Independent Study

Individualization of instruction, in a broad sense, is the general tendency. Even the small-group approach tends to individualize instruction if compared with large-group instruction and can be interpreted as a link between these two instructional modes. This tendency leads to a student centred process in which students have greater freedom to proceed at their own pace and choose learning activities compatible with their learning styles. At the same time the materials provided give the student greater guidance through his study of the subject matter, and offer the opportunity of independent study to a wider spectrum of students than hitherto.

3.2.2 Objectives, Mastery Learning, Criterion Referenced Evaluation

Clearly stated objectives specifying what the student is expected to do, under what conditions and to what level of performance, are a necessary component of study guides and modules. Usually these objectives are associated with the basic assumption that, with necessary learning conditions, they can be mastered by all students. *Mastery learning* [4] is naturally associated with individualized instruction. In a PSI course, for example, the student can retake a unit-test as many times as necessary to master the content of the unit at the level specified by the unit objectives. Student evaluation in mastery learning practices is *criterion referenced* (the objectives establish the criteria) whereas traditional instruction is norm referenced. In the first case the student is essentially in competition with himself to achieve the objectives, whereas in the second case he is in competition with the others to obtain a position on a normal curve.

3.2.3 Personal Interaction, Student Cooperation, Different Type of Student-Staff Relation

An enhancement of personal interaction is usually reported in individualized or small-group courses. Student cooperation and peer-teaching are a natural consequence of small-group arrangements, of the use of proctors and of the simple fact that students are not in competition against each other, since criterion referenced evaluation is used. As the new approaches move toward individualized instruction, the pattern in student-staff relations moves from teacher-dominated activities to student-centred activities with various forms of student-staff cooperation [19]. As a consequence, the student-staff relation is quite informal and personal interaction is enhanced at this level too.

3.2.4 The Role of the Teacher, Team Teaching

As lecturing is strongly de-emphasized, the role of the teacher necessarily changes. He now defines objectives, designs and prepares instructional materials, provides individual assistance, monitors students' progress, gives occasional lectures, encourages the students for good performance, evaluates the system, etc. This is enhanced by teacher cooperation. *Team teaching*, a quite common approach in elementary and secondary schools, is now being used at college level to handle large individualized courses. Basically, the idea is that two or more teachers share the instructional and administrative activities of a course in such a way that teachers as a team plan, conduct and evaluate the course for all students.

The general tendencies identified above are shown schematically in Fig. 1.

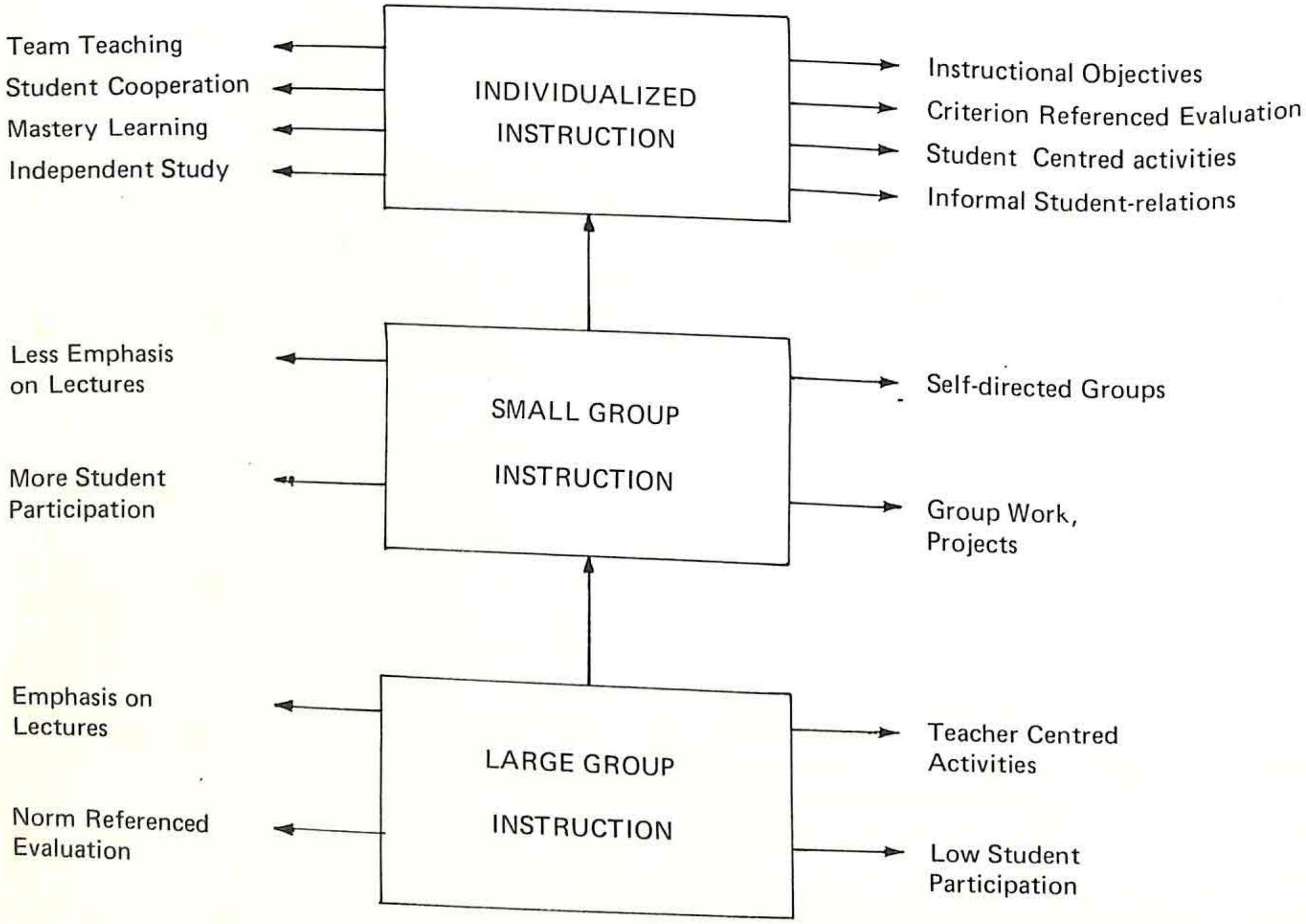
Team Teaching
Student Cooperation
Mastery Learning
Independent Study
INDIVIDUALIZED INSTRUCTION
Instructional Objectives
Criterion Referenced Evaluation
Student Centred activities
Informal Student-relations
Less Emphasis on Lectures
More Student Participation
SMALL GROUP INSTRUCTION
Self-directed Groups
Group Work, Projects
Emphasis on Lectures
Norm Referenced Evaluation
LARGE GROUP INSTRUCTION
Teacher Centred Activities
Low Student Participation

Fig. 1 – Evolving pattern in instructional approaches at university level.

3.3 SOME PROBLEMS AND CHALLENGES

The problems found in the implementation of these new approaches can be tentatively divided into two broad categories: (1) *Administrative and logistic problems*; (2) *Instructional and learning problems*. Some of the problems that can be listed in the first category are:

Cost. In a PSI course, for example, payment of proctors and a large amount of printed materials may significantly increase a course's budget. In an AT or Modular approach a substantial amount of money must be invested to implement and maintain the system.

Lack of teachers and/or assistants (proctors). Usually these are problems related to the cost, but they may also reflect a lack of prepared manpower. This problem makes difficult the implementation of an individualized system of instruction. Small-scale trials, however, may be used to train persons for a future use of the new system on a larger scale.

Course management. Records must be kept, printed materials must be prepared, revised and organized, laboratory equipment must be ready to be used at any time, proctor's work must be supervised, schedules must be organized, etc.

Resistance to innovation. This may come from various sources: an administration that is not receptive to changes in established teaching and grading policies, faculty members who see innovations as some kind of future pressure to change their teaching methods, students with outstanding performances in traditional courses who, under new formats, see everyone being able to obtain an A, etc.

In the category of *instructional and learning problems* the following may be included (not necessarily ranked):

Staff. First of all, the success of the new approaches is heavily dependent on the quality of the instructional materials prepared by teachers (this preparation is extremely time consuming and requires expertise in educational technology). The degree of involvement of the teacher is also a fundamental variable. Another danger is to increase the ratio students/teacher in such a way that the course is ultimately under the proctor's responsibility. As far as proctors are concerned, particularly when a large number is necessary, problems arise in respect of recruitment and training. The success of a PSI course, for example, relies to a large extent on the proctor's performance and this depends not only on his degree of mastery of the content but also on his ability to establish personal relations.

Student dependency. The student may develop an attitude which makes him unable to study without receiving detailed instructions to follow. However, if the study guides are carefully prepared and the instructions change as the student progresses in the course, a high degree of independence in learning may be generated instead of dependency.

Automation may be an undesirable effect when individualized approaches are used with a large number of students. The use of technological devices in education increases the possibility of automation. Modules, AT programmes, computer assisted instruction, etc., tend to mechanize instruction when used with many students. But how can automation be avoided if hundreds and hundreds of individuals must be effectively educated? It seems that some sort of compromise between the use of technology and human interaction in the educational process must be established in order to achieve efficiency.

Many *control rules* must be established when the number of students is too large (e.g. 300 students) and this contributes to mechanizing the course and making it less pleasant.

Procrastination and high number of withdrawals. As the students may proceed at their own pace, some of them tend to procrastinate and, eventually, withdraw. Establishing deadlines for finishing units is one type of solution used. However, it is basically against the idea of self-pacing. Furthermore, these problems may be more related to course programming than to student's ability to self-pace. Too long or too difficult study units, for example, may be a relevant factor influencing procrastination.

Incompleted units. If a syllabus is determined by outside factors such as external examinations, requirements of subsequent courses, etc., the possibility of units not being completed by the students must be taken into account in assessing the use of PSI. From a learning point of view, however, whether partial understanding of a whole course is to be preferred to mastery of a fraction of the course is open to debate.

Cheating and memorized answers [15] may occur. This type of student attitude may be related to programming, i.e., it may be fostered by poorly designed instructional materials. It is rarely necessary to have computer generated tests to overcome the cheating problem.

Lack of content integration may occur as a consequence of dividing the content into small units or modules. This is particularly true when the units are prepared without regard to more general concepts and laws. Review units and a better conceptual organization of course content may be a solution for such a problem.

3.4 SOME SUGGESTIONS

Generally speaking, many problems are likely to be avoided if the innovations are officially supported, if they are implemented by teachers with solid preparation in the subject matter and skilled in designing instructional materials, if they focus on how students learn and if effective methods of assessing the new instructional strategies are designed.

By official support it is meant that the university administration should approve and provide the necessary material and human resources during the experimental phase of an educational innovation. Subsequently, if the innovation effectively improves the instructional and learning processes, additional resources for the implementation and operation of the new system on a larger scale should be provided by the administration.

More specific suggestions to avoid problems and meet the challenges of implementing a new approach are as follows:

(i) It should be tried first with a small group (e.g. 20 students) and the results carefully assessed. If the objective is to run a large course (e.g. 500 students) under the new format, then the number of students should be increased progressively up to the point that the teacher is able to make the necessary extrapolations [8]. At that point he should be able to estimate how many instructors, proctors and aids (secretary, laboratorists, technicians, etc) will be necessary to run the large course. He should also be able to specify the type of facilities, to estimate the amount of printed material, the necessary equipment, etc. Then he should present the results of his first trials and his estimates to the administration to obtain the necessary support. If the support is not provided, it is better not to use the new method. To run a large course under a new format relying only on the work and enthusiasm of a few teachers and proctors increases the probability of problems arising, distortion of the system and eventual failure in spite of the enormous effort made. For example, in a PSI course the ratio students/staff member should not be 'stretched' in order to achieve 'economy'. Usually ratios of 50 students/teacher and 10 students/proctor give good results and are recommended.

(ii) Cooperation from others (e.g. colleagues) in the very early stage of the implementation of the innovation is very important to foster further cooperation and involvement when the new system is applied on a larger scale.

(iii) Direct teacher participation is fundamental. The teacher must interact with the students or groups in the classroom (study hall), laboratory or learning centre, at least during the periods of time officially assigned to the course. He should also evaluate some unit-tests, but he should not act permanently as a proctor because he will lose his mobility. This direct participation has a positive effect on students' attitudes and provides a direct and constant measure of the development of the course.

(iv) Finally, a suggestion about the instructional materials: if they are designed to be used individually they should really attempt to accommodate the range of individual differences. Just dividing the textbook into units (usually corresponding to chapters) and writing uniform study guides usually results in a linear sequence implicitly directed to an average student who is also the target of a conventional lecture approach. In such a case the affective response of the students may be favourable (a positive attitude toward the course) but the cognitive achievement is likely to be no better than that achieved in a conventional format.

Procrastination, a high number of withdrawals and cribbing may be a result of such type of linearity and uniformity in the programme. Students differ in their cognitive structures, skills and learning styles. A rigid sequence of units with the same learning activities in each step, will be adequate only to some students and will generate different reactions from the others. Rote learning and lack of content integration may also be consequences of a bad programme. Branch structure of units could help to solve this problem [6].

3.5 ANNOTATED BIBLIOGRAPHY AND REFERENCES

1. Anderson, O.T. and Artman, R.A. Self-paced, Independent Study, Introductory Physics Sequence – Description and Evaluation, *American Journal of Physics,* vol. 40, no. 12, December 1972, p. 1737–1742. Description of an individualized programme for a three-course sequence in physics.

2. Austin, S.M. and Gilbert, K.E. Student Performance in a Keller-Plan Course in Introductory Electricity and Magnetism, *American Journal of Physics,* vol. 41, no. 1, January 1973, p. 12–18. Comparison between PSI and a lecture-recitation format through a common final examination and a retest taken two months after the course. (Included in section II of *41 Germinal Papers,* edited by J.G. Sherman).

3. Black, P.J., Griffith, J.A.R. and Powell, W.B. Skill sessions, *Physics Education,* vol. 9, no. 1, January 1974, p. 18–22. Description of a small group teaching method designed to help students in acquiring skills which are needed in the practice of physics.

4. Block, J.H. (Ed.) *Mastery Learning: Theory and Practice.* New York, N.Y. : Holt, Rinehart, and Winston, Inc., 1971, 151p. A collection of articles focusing on both the theory behind mastery learning and the operating procedures to implement a mastery strategy in a course, subject or even an entire curriculum.

5. Creager, J.G. and Murray, D.L. (Eds.) *The Use of Modules in College Biology Teaching.* Washington, D.C: Commission on Undergraduate Education in the Biological Sciences, 1972, 173p. A collection of papers on various aspects of modular instruction. Although it focuses on biology, the book is useful for everyone interested in implementing a modular approach in his own course.

6. Elton, L.R.B. Private communication 1975.
Professor Elton, Institute of Educational Technology, University of Surrey provides a Keller course on mechanics in which a branch structure of units is used.

7. Falk, D.S. and Wall, N.S. An Experiment in Undergraduate and Graduate Teaching and an Evaluation, *American Journal of Physics,* vol. 38, no. 17, December 1970, p. 1485–1487. Description of a small

group approach in a graduate course in solid state physics and in an advanced undergraduate course in nuclear physics.

8. Friedman, C.P., Hirschi, S., Parlett, M. and Taylor, E.F. From MIT, Cambridge, Mass., this paper entitled *The Rise and Fall of PSI in Physics at MIT* investigates some of the reasons why introductory physics courses using PSI were discontinued.

9. Green, B.A. Jr. Physics Teaching by the Keller Plan at MIT, *American Journal of Physics,* vol. 39, no. 7, July 1971, p. 764–775. This is the classical paper describing the use of PSI in a physics course. (Also included in section II of Sherman's book).

10. *Guides to Innovation in Physics Teaching,* Stony Brook, N.Y.: American Association of Physics Teachers Publications, 1974. A set of three guides containing a total of 1400 entries giving brief descriptions of college-teaching innovations, name and address of innovators. The first volume lists self-paced courses (PSI, AT and Minicourses), the second focuses on courses for non-scientists and the third stresses innovations in areas like course content and laboratory in courses for physics majors.

11. Jafri, A.V., Ali, A. and Ahmed, R. Stimulating Creativity in Physics – Report on an Experiment. *Creativity and Undergraduate Science Education.* Proceedings of a Seminar held in February 1972 at the Department of Physics, Aligarh Muslim University, Aligarh, India. This describes an experiment in an Indian University in which creativity and divergent thinking were essential objectives in a course which extended over three years.

12. Kahn, P.B. and Strassenburg, A.A. Instructional Innovations in Physics at Stony Brook. *American Journal of Physics,* vol. 43, no. 5, May 1975, p. 400–407. Four innovations are described, in a PSNS course which is inquiry oriented, the laboratory plays an important role. A PSI course is also described. Finally a scheme is presented whereby the students have opportunities to produce instructional materials under supervision.

13. Kaye, A.R. and Pentz, M.J. Integrated Multi-Media Systems. *New Trends in the Utilization of Educational Technology for Science Education.* Unesco 1974, p. 143–176.

14. Keller, F.S. "Goodbye Teacher . . .", *Journal of Applied Behaviour Analysis,* vol. 1, no. 1, p. 78–89. This is the major reference paper in PSI. It describes PSI, applied to a psychology course, as it was conceived by its creators. (Included in section I of Sherman's book).

15. Moreira, M.A. *The Use of the Personalised System of Instruction in an Introductory College Course in Physics during Four Consecutive Semesters.* Working paper for the International Conference on Physics Education, University of Edinburgh, Scotland, July 29–August 6, 1975. Description, data and critical analysis of the progressive implementation of a PSI course from 48 students in the first trial to some 300 three semesters later.

16. Moreira, M.A. and Costa, M.E.V. O Professor como Organizador das Condicoes Externas da Aprendizagem (The Teacher as an Organiser of the External Conditions of Learning), *Revista Brasileira de Fisica,* vol. 1, no. 3, 1971, p. 453–468. Description of a small group approach used on a large scale in an introductory college physics course.

17. Munsee, J.H. An Evaluation of a Nonlecture Technique in the Teaching of Physics, *American Journal of Physics,* vol. 40, no. 8, August 1972, p. 1119–1125. Description of a small group technique used in introductory college physics.

18. Naegele, CJ. *An Evaluation of Student Attitudes, Achievement and Learning Efficiency in Various Modes of an Individualised, Self-paced Learning Programme in Introductory College Physics.* Unpublished Ph.D. Thesis, Cornell University, 1974, 390p. This thesis is concerned with the production, organization and evaluation of an individualized audio-tutorial programme of instruction in introductory college physics.

19. Novak, J.D. *Facilities for Secondary School Science Teaching: Evolving Patterns in Facilities and Programmes.* Washington, D.C, National Science Teachers Association, 1972, 173p. This is a report of a study carried out in some 140 secondary schools in USA. However, the evolving patterns identified by the author may also be applied to universities.

20. Parlett, M.R. and King, J.G. Concentrated Study: A Pedagogic Innovation Observed. *Research into High Education Monographs,* no. 14, Society for Research into Higher Education, London, 1971. A comprehensive description and evaluation of a Concentrated Study physics course. Some other courses are also described and discussed.

21. Postlethwait, S.N., Novak, J.D. and Murray, H.T. Jr. *The Audio-Tutorial Approach to Learning,* Minneapolis, Minn.: Burgess Publishing Co., 1972, 184p. A complete description of the AT system. Although the

description focuses on botany courses, the general ideas apply to any course. The book includes one chapter (VI) on minicourses (modules).

22. *PSI Newsletter,* Washington, D.C.: Centre for Personalized Instruction, Georgetown University. A newsletter designed to provide information about PSI courses and events like workshops and conferences. It also includes short articles on PSI.

23. Sherman, T.G. (Ed.) *Personalised System of Instruction: 41 Germinal Papers.* Reading, Mass.: W.A. Benjamin, Inc., 1974, 225p. A collection of papers designed to serve as a guide to those who wish to use PSI. The first section is concerned with data, method and evaluation mainly in psychology courses. Section II includes papers on the use of PSI in physics and other disciplines. The third section focuses on problems found to implement PSI courses and two remaining sections are concerned with related developments, history and theory of PSI.

24. *The Yellow Pages of Undergraduate Innovations,* Ithaca, N.Y.: The Cornell Centre for Improvement in Undergraduate Education and Change Magazine, 1974, 243p. A general directory of innovations containing name, address and phone number of innovators.

4 The role of experimental work in physics education

This chapter is concerned with experimental work in physics courses at all levels. It is based on an original paper written by J.A. Eades for the Edinburgh conference and on discussions in the working group concerned with this topic at the conference.

4.1 INTRODUCTION

Physics is an experimental science and practical work should therefore play an important role in the teaching of physics at all levels. There are perhaps three principal aims in laboratory work at school level: first to help students to come to a better understanding of the concepts, secondly to help students to appreciate the way in which many concepts and theories are dependent on the results of experimental work, and thirdly to convey certain experimental skills, which will include the design of experiments, measurement techniques, the analysis of data and the interpretation of results. In addition the laboratory is also a good place to pursue some of the more general aims of education – to develop creativity, autonomy and self-confidence, and also to heighten interest and enjoyment.

4.2 EXPERIMENTAL WORK IN THE EARLY YEARS

At the most elementary levels there should be numerous opportunities for children to handle materials themselves, to experiment and to observe. They should have the opportunity to comment freely on physical phenomena without being expected to arrive at some pre-conceived answer. Precise instructions do not encourage that spirit of enquiry which should be fostered when a child first experiences new phenomena. The carefully executed demonstration may do much to enhance the reputation of the teacher, but it does not necessarily encourage that familiarity which everyone would like their pupils to have. The oft quoted "Hear and forget, see and remember, do and understand" is widely accepted as the ideal in the early stages of learning physics.

The working group at the conference felt strongly that in these early stages experiences and experiments should be closely integrated with the development of concepts. This integration becomes less important as the student matures and as his familiarity with physics increases. At all times the physics course should be seen as a unity even if, for administrative or pedagogical convenience, it is presented as a number of subject areas.

In many countries it is evident that there is a need to increase respect for manual activity. The teaching of physics through experimental work can help to establish the dignity and value of manual work and this should be an avowed aim of physics education. In many societies, not only in non-industrial countries, there is a lack of experience or familiarity with materials, tools and equipment of all kinds and this is especially true among girls. To a large extent the early years of physics teaching can provide the experience that is lacking in the home. To help with this, we should encourage the provision of low cost scientific and technologically based toys and construction kits. A fostering of extra curricular activities related to science and technology would also broaden the experience of young people, and this is discussed in detail in Chapter 18.

There is an unfortunate tendency to equate educational merit with complexity of equipment. This can only be overcome by careful attention to the objective of experimental work and to careful preparation of teachers so that they can appreciate the role of observation and analysis irrespective of the sophistication of the equipment. It will be necessary to explain the value of using simple equipment rather than expensive alternatives. Good teaching proceeds from the familiar to the unfamiliar: we are encouraged by the leaders of society to make our teaching relevant. Both of these criteria can be met by more reliance on familiar materials and problems.

4.3 EXPERIMENTAL WORK IN THE UPPER SECONDARY SCHOOL

Although many of the principles mentioned above will apply throughout all levels of a secondary school, there may be a need for some more sophisticated equipment in the later years of school work. Such apparatus can play an important role, especially when it is multi-purpose, provided that it is reliable and does not involve high operational cost and that technical assistance is available to keep it in use. Special teacher training may be necessary on the use and maintenance of apparatus. Workshop training should be an integral part of teacher training.

The objects of experimental work at this stage remain much the same as in the earlier years. Primarily it should help students towards the better understanding of physical concepts, but there is scope for developing further experimental skills.

Written instructions have to be detailed for less experienced students, but they should not assume or predict observations or indicate conclusions. Copious use of drawings, photographs and audio-visual techniques can enhance and simplify such instructions.

Much time is often spent on sterile writing of laboratory reports by students. The working group agreed that if the activity is simple and provided for experience only, laborious accounts of procedure are superfluous. What should be encouraged is the accurate recording of data, analysis and discussion of results, descriptions of difficulties identified and how they were tackled.

The allocation of time for laboratory and theoretical work will have to be made by the designer of a course. The time for individual experiments and activities may range from a few minutes to many hours. In some courses project work, which may involve a student or a group of students for several weeks, is playing an important role. The other thing that is clear is that there is general agreement that experimental work should be a substantial element in all physics courses. When assessing students, adequate weight should be given to achievement in laboratory work, and the actual method and weighting of the assessment should be conveyed to the students.

4.4 EXPERIMENTAL WORK IN UNIVERSITIES

The traditional laboratory course still exists, indeed it is still very widespread. It is built around a set of rigid experiments designed to 'prove' or 'illustrate' the principle phenomena of physics. These should properly be called 'demonstrations' rather than experiments. That such laboratory courses are still so common in universities is much to be regretted as they not only fail to interest the students but positively corrupt them into a false view of science. However, in the last fifteen years there has been a powerful movement away from this kind of work. In a growing proportion of courses much more emphasis is placed on the process of scientific investigation than on the content of the experiment.

The spread of objectives appropriate to laboratory work is so wide that it is not possible to pursue all of them in a particular course and some selection must be made. Unfortunately all too often this selection is not made consciously as it should be, but by default. Since different people in different countries will make different selections, it follows that there are many different kinds of laboratory course designed to fulfil different objectives and in consequence comparative evaluation of laboratory courses is not usually possible. Many of the objectives associated with laboratory work, especially those which are educational rather than scientific, are of a nebulous kind and there does not exist any useful way of evaluating whether they have been achieved. Thus personal convictions, based on the experience of the teachers, play a very much larger role in laboratory work than in theoretical courses.

Although some laboratory work may be directed towards particular skills in certain branches of physics, for example electronics, in general relatively less importance is now attached in universities to specific experimental skills in physics teaching than perhaps is the case in the teaching of other sciences.

Where a laboratory brings together staff (who have experience in research) and students in a low student to staff ratio (10 to 1 say), the structure within which they work is relatively unimportant provided the staff are reasonably enthusiastic and actually work with the students. What is important is that staff and student see each other at work. Unfortunately this situation is rare. Universities where physics is taught as a service subject, for example to medical or engineering students, have sometimes had several hundred students for each staff member working in the laboratory (aided by teaching assistants who are also students). A large part of physics teaching throughout the world is done under conditions which make the teaching of experimental physics through staff-student contact quite impossible.

4.4.1 Trends in universities

As physics advances and the equipment required for research becomes more complex, there is a tendency to introduce more advanced equipment into teaching laboratories, especially in the later years of university courses. This trend towards incorporating experiments which were at the frontiers of knowledge only a short time before serves two purposes. First, both the complexity of the equipment and the topicality of the experiment stimulate student interest and, second, the teaching laboratory becomes much more like a research laboratory. This latter is a controversial point since it can be argued that the similarity is misleading and that students using simple equipment come closer to working like research physicists since they understand more fully what they are doing, and thus the opposite trend also exists where some universities use simpler equipment to reveal and explore a wide range of phenomena, as has already been mentioned above in the school context.

Another trend is towards greater flexibility in the laboratories themselves. The organization of the rooms, the apparatus and the instruments are designed to be used in many ways rather than in single experiments.

In a growing number of laboratories there has been a radical change from the 'cook-book' approach. Detailed instructions for an experiment leave the student little freedom and can even anticipate the result. Mostly motivated to capture student interest, a whole series of laboratory styles have been developed and some will now be considered. All of these have in common an attempt to encourage students to make their own decisions about experimental work.

The open laboratory. As its name implies, such a laboratory is open and available to the students at all times of the day (within limits) when they wish to work in it. In some, the student is offered a choice of experiment and goals, and this develops a sense of responsibility and control over his activities.

The self-paced laboratory. As yet there have been few attempts to establish personalized systems of instruction (PSI) or Keller-plan courses of laboratory work. (The general nature of PSI is discussed in Chapter 3.) However some theoretical courses which have laboratory work associated with them use PSI for laboratory sessions as well.

The instrumented laboratory. In the open laboratory the student will have to make wide ranging decisions about planning when to work and what to do. In the instrumented laboratory the decisions are much more part of the experiments themselves. There is available a wide range of general purpose equipment and instruments, such as might be found in a research laboratory. The student is asked to make measurements or investigate a phenomena without being given an indication of the experimental method to be used. He must improvise with the available apparatus.

The divergent laboratory. This offers the student the possibility of commitment and choice during the experiments by making each experiment a changing experience. The initial part of an experiment is well defined both in method and in what is to be measured. Various ways in which the exploration may be extended are then offered and the student chooses both his own goals and his own methods for the extension.

Project work. The innovations just described attempt to increase the student's freedom and hence his development as an investigator. The logical extension is project work, which is already spreading rapidly in schools. This involves students in a single piece of research of much greater scope than a normal student experiment. They are required to be more mature and much more complete experimentalists. The experiment undertaken is usually chosen to meet two criteria: the problem is reasonably simple and the result is unknown. There can be little doubt that a project is a very good way of ending a student's course. It allows the student to bring together the separate elements of technique and method which he has learned and to apply them in a context which is interesting in itself and reveals a synthesis of what physics is about.

4.4.2 Assessment

Experimental work must be assessed, both for feedback and in order to grade students, and laboratory work should be given a weighting commensurate with its importance. Four general methods are used: (1) continuous assessment of a student's work, (2) assessment of written reports, (3) written examinations, (4) practical examinations. As each of these is useful in evaluating different aspects of student work, it is likely that some combination of them would give the best results.

4.4.3 Proposals for Change in University Laboratory Work

It is obviously important that any designer of a course should first be clear as to the objectives of his course. It will normally be a mistake to arrange a course in which each activity is structured in the same way. A course which does not consider how a variety of experiments can best meet its objectives will be failing to make the most of its resources.

In universities it has been common to separate teaching into three distinct parts: lectures, laboratory work and tutorials (or some other group activity). Recently there has been more integration and it is to be hoped that the full variety of experimental activities will be incorporated into the spectrum of teaching methods available.

It is recommended that more should be done to enrich staff-student contact wherever possible, that special attention be paid to objectives in experimental work and that the barrier between laboratory work and lectures should be eroded.

There is a great need for research on many aspects of experimental work in physics education at all levels.

4.5 BIBLIOGRAPHY

1. Beun, J.A. Experiences with a Free Undergraduate Laboratory. *American Journal of Physics*, 39, 1353 (1971).

2. Chambers, R.G. Laboratory Teaching in the United Kingdom. *New Trends in Physics Teaching*, vol. II, Unesco 1970.

3. Crane, H.R. Experiments in Teaching Captives, *American Journal of Physics*, vol. 34, 1966, p. 799–807.

4. Dixon, B. What are the Guideposts for an Effective College Physics Laboratory? *Science Education*, 53, 33 (1969).

   Discusses the various balances among competing goals and procedures in the laboratory.

5. Dowdeswell, W.H. Teaching Through Projects, *School Science Review*, vol. 51, 1969, no. 174, p. 169–172.

6. Dwyer, Bro. L. The 'How' of Lab. *Physics Teacher*, 11, 425 (1973).

   Examines the results of voluntary grouping of high school physics students in laboratory work. About ten per cent prefer to work alone, some in pairs and others in larger groups. Differences in learning are discussed.

7. Ferreyra, R. Laboratory Experiments and Other Activities in a Multi-Media Approach to the Teaching of Physics. *New Trends in Physics Teaching*, vol. II, Unesco 1970 (p. 197–219).

   Professor Rafael Ferreyra from the University of Cordoba discusses the results of follow-up work and some trials in Argentina and Bolivia, based on the course materials designed and developed by the Unesco Pilot Project on the Teaching of Physics in Latin America.

8. Finegold, L. and Hartley, C.L. An Experiment on Experiments in a Senior Laboratory. *American Journal of Physics*, 40, 28 (1972).

   Two new 'experiments' were introduced into a senior laboratory course: one to design but not to perform an ambitious experiment, the other to select a simple experiment and assemble equipment to carry it out. Some comparisons are made between the performance and attitudes of students who did these experiments with those who did only the regular experiments in the course.

9. Flansburg, L. Teaching Objectives for a Liberal Arts Physics Laboratory. *American Journal of Physics*, 40, 1607 (1972).

   A listing of objectives and examples that 'provide a rationally sound basis for the selection of laboratory content, and . . . are stated in a form that is currently being accepted by administrators and accountability experts'. No trial of the ideas contained is reported.

10. Flinner, J.L. and Giffen, W.C. Term Projects in the Introductory Physics Lab. *Physics Teacher*, 10, 86 (1972).

    Reports on a four-term trial of an innovation in the laboratory for a one-year college physics course for non-science majors. Approx. 100 students did experimental projects of their own devising. Sufficient faculty counselling to get all students started early is essential (two faculty members and one student assistant needed). List of typical term projects. Students strongly agreed that the 'term project was worthwhile'.

11. Harding, A.G. The Project: its place as a learning situation. *British Journal of Educational Technology*, vol. 4, 1973, No. 3, p. 216–232.

12. Hill, D.R. Post O-level project work in physics. *School Science Review,* 51, 176, (1970).

    The introduction of the 'open ended' experimental investigation presents special problems for the teacher of sixth form groups. The article analyses the factors involved in the mounting of short projects which may assist in the initiation of such work.

13. King, J.G. On Physics Project Laboratories. *New Trends in Physics Teaching,* vol. II, Unesco, 1970.

14. Lesniewski, Cz. Rola doswiadczen, demonstracji, pokazow i cwiczen laboratory-jnych w nauczaniu fizyki. *Fizyka w Szkole,* nr 5, 1970, Poland.

    Role of experiments, demonstrations and laboratory exercises in physics teaching.

15. Lewis J.L. Aids in Science Teaching. *Science and Education in Developing States,* Praeger Publishers, New York 1971.

    A discussion of the role of the laboratory in a physics course at the secondary level, consideration of apparatus, textbooks, teachers' guides, films, television and school broadcasting.

16. Lewis, J.L. (ed). *Teaching School Physics,* Unesco-Penguin, Harmondsworth, U.K. 1972.

    A Unesco source book on the teaching of physics at the secondary level, produced in association with the teaching commission of IUPAP. Contains several chapters on teaching with reference to practical work and details on physics apparatus (p. 171–190) and physics laboratories (p. 191–213).

17. Menzie, J.C. The Lost arts of Experimental Investigation. *American Journal of Physics,* 38, 1121, (1970).

    History and philosophy of the introductory physics laboratory in the USA. Listing of primary and secondary goals for the beginning laboratory.

18. Mihm, R.J. Laboratory Experiences: An Approach to Teaching Physics. *Physics Teacher,* 8, 309 (1970).

    Describes a no-lecture high school physics course based on 'laboratory experiences, coupled with dialogues between students and the instructor'. Fifty six experiments are listed, done by pairs of students; weekly examinations are also done by the pair, who discuss the result with the instructor. Discusses physical plant, usefulness of computer, and evaluation; course enrollment has increased from 25 to 120 in six years.

19. Panaiot, L. and Petrescu-Prahova, M. Dezvoltarea gindirii stiintifice prin activitatea experimentala a elevului la fizica. *Revista de pedagogie,* 20, (10) 1971. Romania.

    Devloping the pupils' scientific thinking through experimental activity in physics.

20. Prescott, J.R. and Anger, C.D. Removing the 'Cook Book' from Freshman Physics Laboratories. *American Journal of Physics,* 38, 58, 1970.

    Detailed laboratory instructions in an introductory physics course for physics majors are replaced by a series of questions concerning design execution, and interpretation of the experiments. Frequent reference is made to earlier experiments. Significant time must be spent training graduate teaching assignments in the method. Several kinds of evaluation are made of the four-year experience.

21. Shonle, J.I. A Progress Report on Open-Ended Laboratories. *American Journal of Physics,* 38, 450 (1970).

    Reports a three-semester trial of an open-end laboratory given to second-semester students in a three-semester introductory physics sequence. (No lab in first semester). A preliminary specified experimental exercise with each piece of equipment is followed by a chance for the student to formulate his 'own hypothesis' about the phenomena measured by the equipment; a hypothesis which can then be tested (after clearing it with the instructor). Twenty four students per section is an upper limit. Rather careful evaluation.

22. Sneider, C. A Laboratory and Discussion Approach to High School Science Teaching. *Physics Teacher,* vol. 9, 1971, p. 20–24.

23. Varga, L. *Experiments, made by pupils in teaching Physics.* Publishing House for Text-books, Budapest, Hungary, 1972, p. 234.

    The author had carried on research work for several years in order to determine the most effective working process for pupils' experiments and their educational influence. In his book he sums up his most important basic conclusions and practical suggestions. In the first part there is an account of the experiments, done by the pupils. In the following parts he deals with questions of principle, practical problems (personal and objective conditions, the form of work, etc.) and educational aspects. In the last chapter concrete proposals can be found.

24. Group for Research and Innovation in Higher Education. *Studies in Laboratory Innovation: A set of case studies and commentary.* The Nuffield Foundation, 1975, 70 p.

A set of case studies sponsored by the Nuffield Foundation. Outsiders visited five different university laboratories (in the U.K.) and wrote critical reports of what they found.

5 From school to higher education

This chapter discusses the consequences of the boundary between the secondary and tertiary parts of education in a variety of countries and the nature of the move from school to university in several aspects. It is argued that the relation between school and university is a complex social whole, at least as far as physics is concerned. This edited chapter is based on an initial paper by J.M. Ogborn, modified by the discussion of the working group concerned.

5.1 SELECTION

It is easy to see a discussion of the change from school to higher education as simply a practical debate; an account of difficulties and problems experienced in many countries. But it soon becomes clear that the matter goes much deeper. Indeed, if we pursue it far enough, we find answers reflecting on the very fabric of society. Many will not wish to go so far, but even they have to recognise that the nature of the problems reflects deep seated social structures and values. Dealing with the problems may involve changing those structures or values.

It happens that these influences are particularly clearly exposed to view when we look at the transition of students from school to higher education, at the awarding of high school diplomas, at the way students are selected, and at the arguments that surround these events. We find large differences between countries, as well as many similarities, and these comparisons often have to do with social phenomena – not least, because universities in some countries openly confer potential social power – economic and personal – on those who gain their degrees. The competition to enter university (or other forms of higher education) reflects the way we control the distribution of this power.

At all events, schools and universities do differ from one another. About this nobody would disagree. Indeed, like most distinct but related social institutions, both are at some pains to emphasize the differences between each other. The university teacher is often to be found explaining to students that the university is not like school in one respect or another. When we discuss the problems involved in going from school to university, therefore, we are discussing a gap between institutions that is not wholly an accident of organization, but at least in part a gap which is deliberately maintained.

All social groups feel this need for self definition, and achieve it by differentiating themselves from other groups. Historians contrast themselves with geographers – book-keepers with labourers – 'professional people' from others. And the closer the resemblance, the more detailed is the description of the difference!

Some of the problems then for a student going from school to university are those of going from one well defined social context to another context which tends to stress its different character. But we are discussing institutions that are in many ways similar, so that they strongly emphasize relatively subtle differences between each other. Doctors and dentists, barristers and solicitors, novelists and playwrights, or painters and carpenters, all present similar phenomena. The problems of moving from one institution to a radically different one – from school to work, for example – are very different.

Most of the relevant distinctions are obvious enough. Schools are centres of teaching; universities are centres of learning. Knowledge is passed on in school, but is sought out in the university. Schools are for 'children'; universities for 'adults'. People matter in school, ideas matter at university. Help is pressed upon one at school; at university, help must be sought or be found in oneself. At school ignorance or confusion is more likely to be thought the fault of the teacher, but at university the fault of the student. Schools are (relatively) compulsory, university is (relatively) optional. Universities are selective, schools are less selective. Schooling is thought of as a right, university as a privilege.

None of these distinctions is absolute, but each indicates a dimension along which there is some difference, and a difference likely to be emphasized by those on either side of the institutional divide. Nor need we fall into the sociological error of supposing that to describe is to offer a critique; the differences may be differences that it is important to maintain. On the other hand, we have to accept that the moment of transition is a social fact, which is independent of the individual student's intellectual or emotional development. In certain respects, the differences may act so as to further that development, but in some cases the individual student may not be ready for the social quantum jump he is asked to make at a time not of his own choosing.

Social facts have a way of seeming inevitable and necessary within any one social environment. Here it is necessary to get outside so as to be able to see the situation for what it is. In the next part of this chapter, therefore, we shall contrast aspects of the move from school to university in several countries: Brazil, Hungary, India, Spain, England and Wales, together with some remarks about other countries. The populations and the per capita income of these countries differ by at least an order of magnitude; racial and religious difficulties appear in very different ways; and expectations of students for the future differ no less. These differences are important, but equally important are the similarities.

One similarity is that the actual process of selection is spread over a much longer time than it appears to be when we think of a selection examination. In many countries there has appeared some sort of 'buffer zone', some intermediate stage, between school and university. In Spain and India there are pre-university courses to orient students towards the university. In Spain they are taken at school, in India at university. In France the propeudeutic examination at university used (before 1968) in effect to select those who would continue. Similarly in many countries the first year of university is a year of selection with many students dropping out. This is found not only in several European countries, but also for example in Honduras, where the drop-out in physics may reach 50 per cent. In Brazil, there is both a very selective entry examination and high rate of drop-out. In England and Wales, the sixth form (twelfth and thirteenth years of schooling, ages 16–18) serves as a buffer course, but one taken at school. It is no surprise to find that the work done and the degree of specialization involved are in some ways comparable to what is done in the first year of the bachelor's degree course in, for example, Brazil, India or in the United States. Correspondingly we find in England and Wales that failure in the first year would be a matter of concern, not something entirely to be expected. We also find, that whereas a French, Swiss or Honduran student has the right to enter university if he obtains the baccalaureat or high school diploma, the English student has no such right, being selected (or not) for university after the period of sixth form study on the basis of examination results. In the United States, the system of colleges performs something of the 'buffer zone' function. However, there is an important difference. In the United States, as also in Australia, some education beyond school is thought of as normal for a very substantial fraction of the school population. Higher education becomes, as does secondary education in many other countries, a social if not a legal compulsion for many students. This may make a large difference as it alters the basis on which students have enrolled; it may be less a wish to learn and more a social requirement. By contrast in developing countries, entry to tertiary education may be restricted to only a small fraction of those who qualify. In Kenya in 1975, places could be found for only 1500 students out of 5000 with the necessary qualifications. Such differences alter the situation radically. In the U.K. and in several other industrialized countries, universities compete with each other for physics students, instead of students competing with each other to enter university. Rather few countries have developed alternative structures to give another opportunity to those who miss the chance at the age which society determines for them, although the Open University in the U.K. is one such. Certainly there exist various kinds of tertiary education (technical colleges, teachers' colleges and the like) but such is the need for institutions to define differences between each other that it is no surprise to find that these alternatives become ranked in a rigid ladder of esteem. Such effects could easily frustrate the intentions of those who would like to see created a whole continuum of institutions of tertiary education.

Countries differ in the degree of selection for university and in the rewards that are offered by going to university. Brazil is an extreme example. E.W. Hamburger [16] wrote in 1970:

> "Brazil was known a short time ago as the country of carnival, the country of football and the country of happy indolence. But today a traveller who arrives at our shores in the months of November, December, January or February will find that Brazil is in fact the country of competition for university entrance (vestibular). Newspapers, radio and television – all the media of communication – are at the service of the examination; mock examinations, registration instructions, times and places of examinations, names of successful candidates, interviews with examiners, teachers and students, computer print-out of results and finally, advertisement after advertisement for cramming courses. Carnival takes second place, football is forgotten; the talk is all of the examination. It looks like collective madness. The families of candidates anxiously follow every turn in the drama. The candidates take benzedrine; they study all day and all night; they suffer nervous breakdowns; and as a rule they take several examinations in every kind of university, so as to be sure of a place."

In India, the competition for places can be as intense. But before making comparisons with other countries it is important to remember that it is only the richer countries which can afford to pay students to go to university by giving grants. In England and Wales, for example, any student admitted to university can rely on a grant if it is necessary. In India however there are very few scholarships which bring money with them and the great majority of students have to be supported by their families, find work, or both. Inevitably this reduces the number of young people who are able in practice to aspire to higher education and in one sense this reduces competition.

The rigour of selection has its effect on schools. In Brazil, not only do schools feel bound to focus much of their work on the entrance examination, but there is also a large system of private cramming courses designed expressly and exclusively for that purpose. The rich can better afford these cramming courses than the poor, with the result that the free universities and the private universities both give preference to the rich, in the first case through the very system that was supposed to give a fair chance to all.

Where selection is intense, as in developing countries, or where large numbers are involved, as in highly developed countries, the pressures of fairness and administrative convenience can turn selection into a mechanical, 'objective' process taken out of the hands of teachers. The evidence that no 'fair' system has yet been found is overwhelming, and many find the impersonality of mechanical processes offensive. It might be argued that selection using recommendations from schools supported by interviews, while no more just, would at least bring the injustice into the open where it belongs. And it could have a healthy influence on the style in which physics is taught.

Methods of selection can not only influence the style of teaching in schools, but also the whole curriculum. For example, in England and Wales, until well after the Second World War there were relatively few English university places. A large expansion has recently taken place, but the educational system still bears the marks of the previous scarcity. A university could afford to demand very high standards on entry and this enabled them to reach a high standard of degree work in a Bachelor's course lasting only three years. Schools had to respond by giving a very intensive, specialized course (normally only three subjects are taken) in the last few years of schooling. So it came about that English schools had a more specialized curriculum and English universities a shorter course than can be found in almost any other country. By contrast, the Spanish or French university course lasts longer and students study a wider range of subjects at school. It is presumably no accident that after the recent expansion of university places in England, serious thought is now being given to the widening of the curriculum in English schools. An English student, however, can still be fairly certain of getting some kind of degree once admitted. The numbers dropping out or failing are very small compared to other countries. Here we have an effect of the very selective system, together with the placing of the 'buffer zone' in the schools, not in the universities.

The idea that schools 'lay down the foundations' of a subject, or that previous courses in physics are a necessary pre-requisite for further study may in part be an unconscious message transmitted by the selection system. Departments of linguistics or philosophy (to name only two) admit students with no previous knowledge of the subject because most students have not so far studied it. (These subjects even become thought of as especially belonging to the university level although clearly they need not be and in some countries are not.) In the U.S.A. it is relatively easy to start physics late and in Denmark, for example, it is possible to begin university physics having studied the classics at school. One university in England and Wales offers a four year course in which the first year is common to all students and choices are only made after that year. It must be said that science loses more than it gains as a result.

5.2 THE SOCIETY OF THE UNIVERSITY

The large and prestigious Indian universities, despite the size of the country, are national rather than local, so that students may travel a thousand kilometres or more to attend them. In India, a country containing a large variety of distinct cultures, the change in social milieu that such a student can face is large: different food, dress, customs and language, not to mention religion. The differences may be as marked as if a Swedish student travelled to Italy or to Spain for his university education. Many more Indian students, of course, attend a university or college nearer home, but the contrast with other countries can only increase our respect for the tolerance and fortitude of Indian students. It is still of interest to note that, while most Spanish universities draw their students from the surrounding region, English universities may frequently not do so, a tradition following a long period of few places and a fairly well recognised 'pecking order' amongst universities. In India, as in many developing countries, the problems are compounded by a change in the language of instruction. University teaching is normally in English, while school instruction is normally in the local language. This problem, while one not common elsewhere, is of great importance in such countries. Would English students take well to university courses in

French or in Latin? Brazil is also large and has diverse cultures and so may be fortunate in having adopted the language of those who colonized the country.

In considering the effects of moving into a new society, we should not ignore the importance of the size of the university. A large English university of 10 000 students looks small by comparison with typical Spanish, French, American, Brazilian or Indian universities. Differences in social roles are considerable. French students, for example, live very much in the society of the city as well as in that of the university. They have to find food, accommodation and perhaps work for themselves: being a student is not too unlike any other kind of work. It is not uncommon for a Brazilian undergraduate to teach in high school by day and study physics at night or vice versa. At the opposite extreme, the English university likes to see itself as a small closed society, protective of its students. Such differences could hardly fail to affect the maturity and self-reliance of students. In the universities in large cities, especially in the developed world, student commuters are common. One may doubt whether they benefit as much as they might from the society of the university. On the other hand, many Indian students live at home, and it is less clear that one can assume that a break with home is desirable for them. Not least amongst the changes from school to university are changes in teaching style, in relationships between teachers and students and in attitude to learning. As in most educational institutions, classes are large in size at entry and diminish in size in later years so that a student goes from the smallest class with the most individual attention in one institution (the school), to the largest class in the next institution. It is not surprising that Carolyn Miller in her study of a Scottish university finds that *confidence* is a central issue in the feelings of the first year student. An important change here is the change in attitude of teachers; significantly they are often not even called 'teachers' at university. To go from school to university is to go to a place where not being able to understand, not learning, is now seen as more the fault of the student than that of the teacher. Of course, it is recognised that there are idle students at school and bad teachers at university. But it is still the case that at school the teacher tries to *make* the student learn, while at university the teacher more nearly *permits* him or her to learn.

Both sides could perhaps help here. The school could help by encouraging more independence and ability to learn by oneself. This is easy to say but hard to do, particularly in many less developed countries where more of what is taught seems alien to students and respect for authority runs high. Developed countries could much more easily make efforts in this direction (as in the Nuffield Advanced Physics Course in the United Kingdom). The university could help by looking for more ways of giving students quick and effective information about the standard of their work. It is possibly here that the increasing popular Personalized System of Instruction (PSI) or Keller Plan [11] [14] [15] may have some value, just because rapid and extensive feedback is built into it. It must be recognised however that methods other than mass lectures are hard to manage and expensive to run when classes are large. PSI has been used with large classes, notably in Brazil, but the problems are considerable.

Some countries have universities which can afford to provide personal tuition, this tradition being strong in England and Wales, where tutorial groups of four are common and 'groups' of one are not unknown. In India problem or recitation classes may run from 30 to 60. Brazil is not much more fortunate and such teaching tends to be at the initiative of the teacher, not something built into the organized teaching programme. Work in small groups is done in Spanish and French universities, but is less common and less institutionalized than in England. If group teaching could be made more flexible, easier for tutors to manage and more useful to students [1] [4] [42] it might have special value in the first year, so that students could do more physics in a setting less anonymous than the lecture hall and less isolated than the study or library table.

5.3 KNOWLEDGE

We now turn to what many will consider the central issue. Do students know enough when they arrive at a university? If not, what can be done about it?

Universities can find themselves in a trap. Physics departments need students in order to live. If students go elsewhere, they must take worse students or contract all their activities. At the same time they must at least seem to maintain the standard of the degree. It is no surprise then to find heated arguments about whether the secondary schools have adequately prepared students and to find a tendency to suspect that they have not done so.

The worries about what students coming to university do not know are of several kinds: that they do not know enough; that they do not understand what they know; that they do not understand what physics is and how it works; and that they are unable to learn effectively by themselves. Developing countries stress the problems of a lack of independence of thought, of an unquestioning attitude and of a lack of skill with apparatus. The lack of apparatus in schools is the obvious reason for this last and is the easiest to see how to remedy in principle, if not in practice. An unquestioning attitude may have social origins: on the one hand physics in textbooks and examinations reflects in its examples and language a remote or even alien culture; on the other, there is the dire necessity of succeeding in the learning process if the student is to escape from life-long poverty. By comparison, the worries universities in developed countries have about students' lack of knowledge or differences in their knowledge may seem parochial. When students know almost nothing, it is idle to complain and differences vanish. When students can scarcely do arithmetic or write a description of an experiment, one can be sure they do not understand potential difference.

When the wave of curriculum renewal began two decades ago in the English-speaking countries attention was given to the way in which students seemed to have learned large numbers of facts, unrelated by a deeper understanding of ideas or by an appreciation of their significance in scientific argument. New curricula in physics were devised which gave less attention to factual detail and more to concepts and ideas [35]. Later curriculum development has paid more attention to the methods of physics and to its history (for example, Project Physics). It has also encouraged independence and the ability to learn from books and discussion (for example, Nuffield Advanced Physics).

It would be facile, however, to blame modern trends in science teaching for a deficiency, real or imagined, in the amount of knowledge students have. Few such new programmes yet affect more than 10–20 per cent of the relevant population in the schools and those familiar with schools will testify that, despite many large changes, physics teaching very often looks to the impartial observer much as it always did. Other changes, notably the continual expansion of secondary and of university education in very many countries, may have produced no less noticeable effects.

In England and Wales, one response to such worries has been the Nuffield Foundation sponsored Physics Interface Project in which six British physics departments participate [43], [44]. This project (one of several in a wave of curriculum development at university level) is concerned with the gaps in the knowledge students bring with them to university and the resulting difficulty of mounting coherent first-year courses. The project is trying to devise diagnostic tests and materials to help students overcome some common deficiencies. It might be thought that, if there is a problem, it is a peculiarly English one produced by the existence of ten examination boards each with its own syllabus instead of one national examination. However, studies by the Project suggest that more important than syllabus differences are two other factors: the interpretation teachers put on the syllabus (using past examination papers) and, related to this, the way teachers and students 'play the system', taking calculated risks in omitting sections of the syllabus which they take to have relatively low priority in the examiners' minds. If the project is right in this diagnosis, it could have implications for other countries in which there are strongly selective university entrance examinations.

In countries such as the U.S.A. or Australia, where higher education is more nearly universal, it is the university which has to make provision for what the student does not know, rather than the student being expected to repair gaps in his knowledge on his own.

In India, as in many other developing countries, there is another set of problems. Lack of competence in English (the medium of instruction) worries many students and sometimes teachers themselves do not command the language well enough to use it really effectively in teaching. Social tensions are not unknown and financial problems are manifest. Books are costly, those by Western authors being hard to understand and those by Indian authors being few in number. The most popular forms of book are in question and answer form, containing nothing but previous examination questions and answers to them. The reaction to such books is ambiguous; they are felt to be deplorable in many ways, but they are also felt to suit the Indian student. Students able to repeat back large amounts of memorized information are common. They are to some extent rewarded by the system of teaching and – having regard to traditional Indian values – are treated with more respect than scorn.

By contrast, in English-speaking countries the expansion of university education, changes in the curriculum and (in some cases) changes in the organization of secondary education have caused fears that things of value in the older curriculum may be lost. Teachers are perhaps now more inclined to worry about whether their students will be as good as they were and about whether the good ones will know as much as good students used to. The added variety amongst curricula is a further worry, making it seem harder to plan introductory courses. There is also a small but persistent worry that schools, in making physics more stimulating, may have taken away from universities some of the more interesting topics, leaving them with more dull material to teach.

In university thinking about teaching there is a tension between two opposite views: firstly that physics is physics and has got to be learned whether students like it or not if standards are to be maintained; and secondly the need to attract students in a market which at best fluctuates and at worst declines steadily. Some resolution of this internal conflict might help, perhaps if physics teaching were thought of as a means to education rather than as the acquisition of a body of material in which students must necessarily be instructed.

A comparison of Hungary with these other countries throws into relief some of the underlying problems. The number of places is decided centrally in line with employment planning (explicitly instead of indirectly as in many other countries) so reducing inter-university competition for students, though the competition for places is intense. The university system is seen as a part of a planned social system: university education is free for the five per cent or so who gain admission, but is not a right. (By contrast, in France the cost is also low, but large numbers of students enter and are later filtered out.) In Hungary the drop-out rate in the first years is essentially zero. Students are reported to be glad of the chance to be at university and to be correspondingly diligent.

Social facts are highly relevant to the comparison. Whereas in Brazil, the possession of a degree may improve later salary prospects by as much as a factor of five, in Hungary a Reader may expect to earn about the same as a bus driver. Paradoxically this may reinforce rather than diminish the strong preference for university courses shown by parents of children in educated families: it is they who are well enough aware of the arguments to encourage their children to try hard when the advantage to be gained is access to more interesting work rather than to higher incomes. Hungary has found it necessary to give some preference to children of less educated families in its selection system. In this we see an effect which, sadly, appears to be general. All over the world the more educated families seem to be more successful in getting education for their children than are less educated families.

Like many comparable countries, Hungary has a long tradition of respect for knowledge. There a university teacher is likely to regard it as his duty to help students and to suppose that their ignorance is not so much their fault as his, a feeling connected with the place of the university in a socialist society.

The selection system reflects the value system. In Hungary, with small scale industry, independence and creativity are valued in a physicist. For Indians, as for others in many developing countries, entry to university is seen simply as entry to employment, so that even courses (often in India actually called 'papers') are seen as part of social selection. Yet again, where the university is seen as the source of future leadership, selection has another social meaning. These differences influence schools, and what they value. It can be no accident that the French respect abstraction and theory, and that French society esteems highly the Grandes Ecoles, with their highly abstract and theoretical courses.

5.4 STRUCTURE AND CHANGE

We will now consider the forces which make for change in the relationship of school and university and those forces which make for stability. The reader will have detected little trace in the discussion so far of any pattern corresponding to an influence of changed educational thinking in schools on thinking in universities, or vice-versa. In this sense no 'trends' of the kind the reader might expect have been reported. Universities are not noticeably planning and restructuring courses either in response to changed thinking in schools or as an independent venture in curriculum renewal on any comprehensive scale. Instead of trends, we see individual responses: responses to a real situation whether economic, political or social, not responses to a changed educational situation.

The first point to consider is the relation between curriculum change and structural reform. Just because schools and universities define themselves as distinct, changes affecting their relationship have often to be structural reforms: changes in the rules. By contrast, the world-wide wave of curriculum renewal in the schools involved hardly any structural reform. Indeed it is notable how often these projects took the current structure as a fact of life to which they had to accommodate. We may cite as examples the Nuffield projects in England and Wales which were affected by changes in the system soon after publication (a shift to comprehensive schools in the case of the 11–16 O-level project; attempts to reduce specialization in the case of the 16–18 A-level project).

In many countries, structural reform is much more directly connected with relations between schools and universities than is curriculum change in either. Attention here, not surprisingly, focuses on the selection examination. In Spain, the special selection examination following the pre-university course was abandoned for a time, in favour of a system of qualification closer to that of the baccalaureat. Universities experienced a large increase in numbers over a short period, and the selection system is currently being re-introduced. Few if any curriculum changes accompanied these reforms and at present Spanish teachers in schools complain of a paralysingly large syllabus and the need to teach physics in an almost wholly formal mode.

Hopes for a reform of the school curriculum via control of the vestibular (university entrance test) once ran high in Brazil. Little was achieved, though reports suggest that the changes concentrated wrongly on improving the technical quality of the questions rather than their nature.

In the Netherlands, changes in university curricula have been ascribed to structural reform of the university system rather than to a need to rethink education at this level. And it is notable that in England and Wales, a debate over the last ten years about reform of what is the most specialized system of pre-university education in the world has been almost wholly independent of curricular reform.

Another relevant facet is the structure of the national education system. Like many other countries, France, the Netherlands and Hungary have centralized systems. In such a system it is possible to reform by decree. Paradoxically this may make reform much more difficult. There have been cases where it seemed unreasonable to educational administrators to allow a pilot trial on a small scale in the interests of uniformity. They required reforms to be implemented wholly or not at all and this imposes a limit on how radical the reforms can be. An essential right, the right to be wrong, has been taken away. Here the Anglo-Saxon countries have been fortunate in their relaxed empiricism: change in a marketplace educational system is tolerated. But the consequence is that the influence of change is automatically limited. Instead of reacting to change in the schools, universities cautiously wait and see whether the changes will spread or gradually be forgotten. In the meantime, conservative (or if you prefer, conservationist) forces operate to limit change. In so far as university courses do not change, school teachers feel bound to reduce the level of innovation in the school course out of fairness to students. In more centrally organized systems, wholesale change can be decreed on paper. Problems of the dissemination of curricula are outside the scope of this chapter, except that we should note that in many cases the decree has not been matched by the huge scale of teacher retraining that is needed (or the scale has been underestimated) so that change has again been self-limiting. The consequence is that in both types of system changes are slow in real terms with a tendency to backlash in centrally organized systems. It follows that universities have as yet relatively little to react to as regards changes in the school physics curriculum. They *hear* of changes, but the students look much the same as before.

In passing we may note that in country after country university teachers do not in general seem to know very much about what has changed in the school curriculum. We need not assume idleness or indifference as an explanation. It is enough that education is complex, that a curriculum is not to be defined in a few lines of syllabus and that there is no channel for complex information to flow along. There is none of that seeing which might lead to understanding, let alone believing.

Relatively small countries, in which we can include some but not all developing countries, have the advantage in that communication is potentially easier. Good liaison, for example, occurs in Sweden, in Scotland and in Northern Ireland.

What do we see when looking at students going from school to tertiary education? To begin with we see students confronting a selection system, not always for the first time, but one of the most rigorous they have met. In some countries they are competing for social advantage. In many countries they meet for the first time a part of the education system which tries to prevent a substantial fraction from entering it, a system with a strong idea about who is suitable to profit from its services.

The competition for places is defined in terms of knowledge of subjects rather than, for example, of wide reading or creative flair. The means used to examine that knowledge have a powerful backlash effect on the teaching leading to it. More personal, more flexible means of selection are needed, not least because they would expose injustice at the point where it was occurring. It is not enough, however, to abolish external entrance examinations. Experience in Canada and Australia suggests that special examinations set by all kinds of bodies spring up in their place.

In those countries which have experienced the recent wave of curriculum change, curriculum projects have tended to challenge the definition of physics held by the university, though often in response to a feeling from universities that the system has too frequently produced students with much information, but with no view of physics and little of the intellectual skill physics might be hoped to encourage. Such a diagnosis still persists in many countries in which the school curriculum has remained stable. Where changes have been made, universities become worried that valuable features of the status quo might be lost.

Universities are anxious about numbers as well as about standards. In the developed world, physics is less and less popular, while in developing countries they have to cope with very large numbers in very large classes. With the increased demand for higher education efforts are needed to move closer to Newman's idea of a university, "An alma mater, knowing her children one by one, not a mint, nor a foundry, nor a treadmill".

Universities need to develop more their ability to respond to students, to match courses better to what students know. Here diagnosis of students' difficulties is an important tool and there is need for greater flow of information between secondary and higher education. Workshop meetings between teachers from school and teachers from higher education can help, especially if they lead to changes in the university curriculum.

Ultimately higher education is responsible for the standard of physics education in schools: the teachers learn what physics is at college and the selection system affects what is taught and how it is taught. Nowhere is this clearer than in newly independent countries which have to build up their own school systems. In such countries universities have a duty to the school curriculum.

No longer is it the case that higher education means only one thing – the university. Varieties of higher education have developed and their further development is to be encouraged. Not only do we need a variety of kinds of institution, but also variety within institutions. We need a variety of courses and more important still a variety of routes through higher education. Students should have opportunities to enter having previously done other subjects, to change their interests and to withdraw temporarily to return later. Each of us learns throughout his or her life and knowledge certified by diplomas or degrees ought not to be restricted to a particular phase of life.

Ultimately both schools and universities have to resolve (or at least to see clearly) the conflict between education as conservation and preservation, and as development and change. Education recreates knowledge in new generations. It also recreates social patterns in new generations and some of them ought not to be preserved. On the other hand it can generate change; it can encourage people who can make new knowledge and people who can make new societies.

5.5 SELECT BIBLIOGRAPHY

1. Barbenza, G.H., Miguel, O. A teaching strategy to develop physicist's skills early. *American Journal of Physics* 40, 256 (1972).

   Trial in Argentina of a programme to develop confidence, interest, critical thinking and creativity in first year students at university.

2. Bednarik, M., Siroka, M. Contribution to the objectivisation of entrance examinations in Physics at the faculty of natural sciences, Palacky University, Olomouc. *Acta Universitatis Palackianae Olomucensis,* Physics XI 1972.

   Illustrative of the concern for quality in entrance tests.

3. Bernstein, B. On the classification and framing of educational knowledge, in Young, M.F.D. (ed) *Knowledge and control* Collier-Macmillan 1971.

   A sociological contribution to understanding why subject boundaries exist in education.

4. Black, P.J., Griffith, J.A.R., Powell, W.B. (1974). 'Skill Sessions' *Physics Education* vol. 9, No. 1, January 1974, p. 18–22.

5. Black, P.J., Ogborn, J.M. The higher education learning project (physics) *Physics Education* vol. 8, 1973.

   Discusses the proposed development of ideas for improving the quality of interaction between teachers and students at University.

6. Black, P.J., Ogborn, J.M. The Nuffield physicist in the university. *Physics Education* vol. 7, February 1972, p. 66.

   Outlines for university teachers problems and possibilities following the introduction of the Nuffield 16–18 course in schools.

7. Bourdieu, P. Systems of education and systems of thought. In: Young, M.F.D. (ed) *Knowledge and control* Collier-Macmillan 1971.

8. Brown, S.C., Clarke, N. *The education of a physicist* Oliver and Boyd, 1966.

   Many viewpoints distinctively held by university teachers are reflected in this volume.

9. Buvari, A. Fetishised solving of problems and its physical essence. *Fiz Szem* 19, 371–374, 1969.

   Illustrative of the kind of concern which has led to curriculum change.

10. Dubin, R., Traveggia, T.C. *The teaching-learning paradox* University of Oregon Press 1968.

    Reviews 40 years of research comparing teaching methods. Result: there are no differences that amount to anything. A book to depress those who believe in education as neutral technique; to please those who do not hold with new fangled nonsense; and to make the rest of us wonder what we do believe in.

11. Friedman, C.P. A model for improving advanced courses in physics, *American Journal of Physics,* vol. 40, 1602 (1972).

    Discusses use of self-study (Keller Plan) for improving the nature of the course and work done.

12. Geller, Z. Le programme de Rehovot: retrospective et avenir. *Methodica* 1974, University of Tel Aviv.

    Review of a major curriculum development in Israel.

13. Gillon, P., Gillon, H. (eds). *Science and education in developing states* Praeger Publishers NY 1971.

    Illustrates the analysis of deficiencies of school teaching in terms of too narrow a perspective. Looks at Asia, Africa and Latin America.

14. Green, B.A., Jr. Physics teaching by the Keller Plan at MIT. *American Journal of Physics* vol. 39, 764, (1971).

    Describes the Keller Plan self-study method in physics.

15. Green, B.A., Jr. Is the Keller plan catching on too fast? *J. Coll. Sci. Teach* vol. 1, 50, (1972).

    Discusses problems with self-paced study.

16. Hamburger, E.W. O exame vestibular e os desajustes do sistema de ensino (The university entrance examination and its effect on the education system) *Cienca e Cultrua* vol. 22, No. 2, 1970, p. 223–228.

    Discusses the nature of the Brazilian university entrance examination, and its far reaching influence on the curriculum, on teaching methods etc.

17. Havelka, B. *Non-traditional Physics teaching in optics and mechanics.* Nove pojeti vyucovani fyzice na gymnasiu, Sborník referatu a sdeleni prednesenych na konferenci v Luhacovicich 1971 J.C.M.F. 1971.

The article is an example of pressure for courses which stress comprehensive insights rather than details.

18. Holton, G. Issues for the Seventies. *Physics Teacher* vol. 8, 229 (1970).

Looks at relations between schools and universities.

19. Jafri, A.V. (ed). *Creativity Newsletter* Physics Department, Aligarh Muslim University, Aligarh U.P., India.

Reports attempts to teach physics at university so as to encourage creativity and independence.

20. Jonker, C.C. Stand van de natuurkunde aan de universiteiten *N.T.v.N.* 37, 216 (Situation of physics at universities). Responses to structural change in university education.

21. Kaspar, E. Contemporary problems of secondary and technical schools. Sbornik vybranych stati z vedecke konference matematico fyzicalni, University Karlova, Praha 1972.

Reports use of methods stimulating participation and activity at Karlove university.

22. Kaspar, E. The modernisation of school physics-illusion or reality? *Pokroky M.F.A.* 1972, vol. XVII, no. 4.

Illustrative of the debate about changes in the curriculum.

23. Lewis, J.L. (ed). *Teaching school physics* Penguin/Unesco 1972.

See especially chapter on evaluation and examinations.

24. Mackenzie, N., Eraut, M. (eds). *Teaching and learning: an introduction to new methods and resources in higher education,* Unesco 1970. Emphasis on education as technology.

25. McFarlane, J.C. First year physics at four universities in New South Wales – a summary. *Australian Physicist*, vol. 6, 74, (1969). Data relevant to change in courses.

26. Menzie, J.C. The lost art of experimental investigation. *American Journal of Physics,* vol. 38, 1121, (1970). Traces the origin of the classic form of introductory laboratory. An essay in educational realism.

27. N.T.v.N. Special issue of the Netherlands journal, devoted to collaboration of secondary education and university education in physics. *38* no. 6, 1972.

28. Nuffield Physics (1969). *Teachers Guide I*, Longmans, London.

29. Nuffield Advanced Physics (1972). *Teachers Handbook,* Longmans, London.

30. Open University *Course E283 The curriculum: Context, Design and Development.* Open University Press 1972.

Contains much material from development projects, illustrating the complex nature of the forces involved.

31. Open University *Selection at eighteen plus,* unit from Course E282 Open University Press 1972.

An elegant and detailed comparison of the English and Scottish selection system, raising fundamental issues of general interest.

32. Parlett, M. Undergraduate teaching observed. *Nature* 223, September 1969. Methodologically useful description.

33. Parlett, M., Miller, C.M. *Up to the mark: a study of the examination game* S.R.H.E. 1974.

Research studies based on interviews with students and staff, of patterns of belief and behaviour influenced by examinations. Looks at many aspects. Offers some new conceptualizations of problems.

34. Physics International Panel, Report submitted to the West African Examinations Council. *Journal of the Science Teachers' Association of Nigeria* Vol. 5, no. 4, 1966.

Illustrative of the problems of negotiating an examination which serves university entrance.

35. PSSC (1960) *Physics,* D.C. Heath, Boston.

36. Project Physics (1970), Holt, Rinehart and Winston, New York.

37. Prescott, J.R., Anger, C.D. Team teaching freshman physics. *American Journal of Physics* vol. 40, 311, (1972).

Experiments in sharing teaching, so that students are better able to join in discussions.

38. Renner, J.W., Lawson, A.E. Promoting intellectual development through science teaching *Physics Teacher* vol. 11, 273 (1973).

Suggests that many students do not yet function intellectually as teachers expect in first-year university courses.

39. Rogers, E.M. *Mejoramiento de la Ensenanza de la Fisica mediante la construccion y discusion devarios tipos de pruebas* (Improvement of Physics teaching through the construction and discussion of various types of test) Unesco.

Report of workshop at Montevideo, giving examples developed at the workshop, and much discussion. Strongly connects tests and value judgements.

40. Rogers, E.M. Examinations: powerful agents for good or ill in teaching. *American Journal of Physics* vol. 37, 954, (1964).

Required reading for all concerned with testing.

41. Strassenburg, A.A. The evolution of physics teaching. *American Journal of Physics* vol. 40, 1730 (1972).

Traces the recent development of physics teaching, with reference to curriculum development projects.

42. Swartz, C.E., Zipfel, C. Individualised instruction in introductory physics. *American Journal of Physics* vol. 40, 1436 (1972).

Report of a large scale course using flexible methods.

43. Sutton, R.A. The school-university physics interface project. *Physics Education* vol. 7, May 1972, p. 212.

Describes the intention to develop diagnostic tests to enable students to remedy deficiencies from previous work at school.

44. Taylor, C.A. The Physics Interface Project. *Physics Education* vol. 8, March 1973, p. 109 (See Sutton 1972).

45. Thomson, R. Schwarz, G. The College Board Physics Achievement Test. *Physics Teacher* vol. 7, 143, (1969).

Description of an important selection mechanism.

46. UNESCO. *New trends in physics teaching vol. II* Unesco 1972.

Contains papers illustrating approaches to topics and teaching methods, notably laboratory work in universities. See also the chapter by E.M. Rogers on assessment.

6 Educational technology in the teaching and learning of physics

The combination of approaches, methods, media and materials chosen to help the student to learn is called educational technology. It does not mean simply the totality of technical aids used in education which are, of course, examples of technology in or for education. It means the technology of education – a method or approach combined with the necessary media and materials to bring about improved teaching and learning. Learning programmes begin with a statement of what the student should be able to do at the end, that he or she was not able to do at the start; these programmes culminate in an assessment which measures the success of the operation in terms of achievement. The proof of learning lies in the ability of the student to do what was intended.

Educational technology, thus defined, is a theme so broad that various aspects of it have also been assigned to other chapters. Hence, this chapter is limited to selected aspects of technology in education. The chapter is based on a paper written by A. V. Baez.

6.1 EDUCATIONAL TECHNOLOGY: DEVELOPMENTS AND TRENDS

In deciding which topics to choose, we have observed the relative weight given to them in the *Survey of Literature on Physics Education* [1] and in other reviews. In the *Survey* which has information from 20 countries, it was found that 68 entries dealt with the computer in physics and science education, 33 dealt with behavioural objectives and programmed learning, 28 dealt with all aspects of audio-visual aid (films, loops, slides, filmstrips, overhead transparencies, audio-tapes and multi-media) and 17 dealt with television and radio (including closed-circuit TV and video-tape).

Other important topics related to educational technology were (i) the role of the laboratory and experiments – including kits – in physics education (25 entries), (ii) individualized learning, with special reference to the Keller Plan (31 entries), and (iii) evaluation procedures and examinations (13 entries). Topic (i) is dealt with in chapter 4, topic (ii) in chapters 3 and 7 while topic (iii) is considered in 12. They will not be included in this chapter and the discussion will therefore be limited mainly to programmed learning, audio and visual aids, multi-media and audio-tutorial schemes, radio and television and the computer in physics education.

Programmed learning belongs in a special category because it is intimately associated with the formulation of behavioural objectives, and, in fact, with much of what has come to be known as educational technology. By including programmed learning in this chapter we will consider not only the 'things of learning' but also one of the basic ideas that has generated a broader concept of educational technology.

There are two reasons why educational technology should be considered. One is quantitative – the hope that larger numbers of students can learn with the help of educational technology. The other is qualitative and is probably the more important. Educational technology holds the promise to improve teaching and learning strategies. The goal is: better learning for more people through improvement in the efficiency of teaching-learning strategies.

6.2 PROGRAMMED LEARNING

The term 'programmed instruction', often linked with the pioneering experiments and theories of B.F. Skinner and with 'teaching machines', has more recently given way to the term 'programmed learning' to put the emphasis on learning rather than on teaching, although the original term is still often used as a synonym. Thus Leith [2] says:

> "programmed instruction is a set of techniques and principles for designing effective learning situations. A programme is therefore a means of ensuring that students achieve intended objectives."

This sentence suggests that the basic idea of educational technology stems from concepts of programmed learning, an idea which is reinforced as we read further:

> "This is accomplished by carrying out analyses of objectives, as well as of learning tasks involved in their achievement, of learning processes which students must employ and conditions (including media) which facilitate learning. In addition, the instructional materials and their environment must be set up and tested. That is, the programmer must try out his programme and obtain feedback to discover what modifications are needed for students to master the task. During its evolution a number of relatively restrictive models were developed which were initially regarded as rivals. It is now recognised that the earlier forms of programme limit development too much and a generalized systems approach is what characterises programmed learning.
>
> "Almost all of the early 'rules' have now been demonstrated to be invalid and many programmers show a sceptical disregard of the 'essential' rules. Indeed, those which now appear to be critical are:
>
> a. Formulation of objectives and criteria of successful achievement
>
> b. Analysis of tasks and design of learning situations
>
> c. Validation of learning situations and evaluation instruments
>
> "In particular, ideas that programmed learning is self-paced individual learning have been abandoned. For example, it has become clear that group-paced learning is often as good as or better than self-paced learning. This has opened the way for the employment of audio-visual media and much greater effectiveness when, for example, television lessons are programmed."

Even though Leith no longer demands self-paced individual learning as a part of programmed learning, it is one of the essential features of the highly successful Keller Plan to which the reader is referred in chapter 7.

Other writers have stressed that there are four important parameters that must be dealt with, and usually in the following order. These are:

a. Identification of the target population

b. Statement of the objectives

c. Selection of the content

d. Selection of the appropriate medium and mode of delivery

This is a theoretical order, in a real (as opposed to an ideal) situation it is not always possible to follow it.

The geographical spread and the range of projects in which programmed learning has been utilized in physics education is suggested by the list of topics in Appendix 1.

6.2.1 Problems and Challenges

Some of the problems that attended programmed learning in the early days stemmed from the fact that manufacturers produced some very poor programmes, apparently in an effort to enter a market which they felt would be lucrative. The poor quality of these programmes had a counter-productive effect.

Strict adherence to what were considered the rules of programming in the early days also produced some very boring programmes. Boredom for the brighter student has always been a problem which has been partly resolved in modern programmes by permitting the use of other media such as films and the use of laboratory kits as part of the programmes. It is time-consuming and expensive to produce good programmes but the possibility of using them on a large target population makes the challenge an interesting one.

6.3 AUDIO-VISUAL AIDS

For centuries the most widely used visual aids have been the printed book and the chalk-board. Because of their effectiveness they will undoubtedly continue to be utilized. But today, a host of new devices exists which can be used to inform and motivate both visually and through recorded sound, in some cases more clearly and dramatically than through book and chalk-board. Our purpose here is not to downgrade the book and chalk-board but to draw attention to the new devices which may be utilized to improve physics education.

Berman [2] has produced an exhaustive taxonomy of educational media containing eight categories of visual and eleven categories of auditory representations. He treats filmstrips and slides, overhead projection, audio-tape recordings and motion pictures from the point of view of educational technology merely as media subsystems.

Lewis [3] has considered the application of these devices and their corresponding materials to the teaching of physics. We assume that the interested reader will consult these excellent sources for details on their production and use. Because of limited space we take a rather down-to-earth point of view and discuss only the most commonly available types of modern audio and visual aids, namely, 35 mm slides and filmstrips, the overhead projector, audio-tapes for ordinary reel-to-reel and cassette tape recorders and sound and/or silent motion pictures in 16 mm or Super-8 formats. Radio and television and multi-media applications will be treated separately.

The order in which they were named is that in which we believe audio-visual aids should be considered by the practising teacher of physics because it is the order of increasing cost of the corresponding devices and materials and hence of the possibility of access to them.

6.3.1 Slides and Filmstrips

Anything, real or in graphic form, that can be photographed, can be converted into a filmstrip or slide with a 35 mm camera.

6.3.2 The Overhead Projector

The latest version of this instrument is so light that it can be carried easily in one hand from one room to another. The light is so intense that the classroom does not need to be dark. Transparencies can be quickly and easily prepared by writing on them with felt pens or by copying printed material on them with a thermal copier. Overlays, that is combinations of transparencies, can be used to present a complex picture step-by-step. The projector can also project real miniature equipment for experiments. With the use of polarisers, motion can be simulated. The job of producing transparencies for the overhead projector can be undertaken even in financially depressed countries. As with slides, there are considerable advantages in combining the overhead projector with audio-tapes.

6.3.3 Audio-tape Recordings

Recorded speech can be delivered from a portable tape player to an auditorium seating 500 or more with a clarity which far exceeds that of a lecturer speaking without the aid of amplification. Tape-recorded sound can therefore be used very effectively in conjunction with slides and overhead transparencies.

6.3.4 Films

Films are capable of producing a more realistic approximation to experience than any other visual aids. Their advantages in physics teaching are well described by Lewis [3]. Nevertheless, it is easier to be convinced of the great power of film than it is to produce good physics teaching film.

The accepted norm for classroom use is the 16 mm optical sound track motion picture projector. It is found in practically every country in the world. 16 mm film can be reduced to Super-8 mm for use as silent cartridge-loaded single-concept film and this is the usual way it is done commercially. But inexpensive Super-8 mm cameras and projectors are now available and some teachers and students are producing their own physics teaching film with them. Perhaps this will create the interest that will, at last, make film a more widely used medium.

Good films are expensive. To produce a high quality commercial 16 mm physics teaching film costs between £500 and £1000 per minute of final projection time. The cost per student goes down only if large audiences can be reached (as they can through television). In countries where educational authorities are highly centralized it should be possible to take advantage of this, but, in fact, it is probably in some countries where educational authority is most diffuse that the greatest number of physics teaching films have been made. The educational advantages of having students and teachers themselves produce inexpensive films should not be overlooked.

Audio-visual topics from the *Survey of Literature* cited earlier are tabulated in Appendix 2.

6.3.5 Problems and Challenges

Several factors have militated against the production of physics films and their proper use. First, it is expensive to make really good films in physics. This is due in part to the fact that many of them require the showing of experiments, some of which are costly or time-consuming to set up. They also require cooperation from physicists who participate in the writing of scripts, supervise the performance of the experiments and are on hand when the actual shooting takes place to be sure that nothing goes wrong with the experiments and that no erroneous statements concerning physics are made during the shooting. In fact, it requires team work involving physicists, practising teachers, workshop and laboratory technicians, script writers, film directors and producers.

In the case of the Open University, incidentally, the producer is a film maker on the permanent BBC staff with a Master's degree in physics and the team includes a member of the staff of the Institute of Educational Technology usually with a degree in psychology. At shooting time, of course, there is a full studio staff for lighting and camera work. In some small operations, such as the Unesco Physics Pilot Project in Sao Paulo, several of these roles were played by one individual. The success of the PSSC and Open University operations was due in no small part to some form or another of this kind of team work where a great responsibility was given to the physicist.

Commercial firms such as the Encyclopaedia Britannica Educational Corporation have produced some physics films and film loops by hiring individuals as consultants to play one or more of the above roles but the commercial risk factor in making such films is high. No matter how good a film may be, if it is not backed up by a good distribution system it will not sell.

Many films at the high school level utilized physicists as narrators or lecturers. In spite of a long and successful teaching experience, a high proportion of these did not project successfully on film. Quite a few films have been made which are simply filmed lectures with the camera trained on a lecturer, and not enough advantage is taken of the full range of cinematographic techniques which could really have 'brought the world to the classroom'.

Another drawback is the lack of proper projection facilities in most schools and universities. Some of them do have an auditorium which can be properly darkened for special showings to large audiences, but ordinary classrooms are seldom adequate for motion picture projection.

Teachers do not know how to get the best advantage from films. It requires preparation. They need to study the film before showing it so that they can use its contents as the basis of further discussions. Most teachers have too heavy a teaching schedule to permit this.

The short, cartridge-loaded silent 'single concept' film loop is extremely simple to load. The projector requires no threading. The fact that loops are silent was supposed to be an advantage because it does not 'rob' the teacher of the opportunity of doing the explaining himself. But, again, unless the teacher has studied the film carefully in advance, he will not be able to explain it while it is in progress, with the result that the point of some of the films is missed by both teachers and students.

A heavy blow was dealt to the use of loops worldwide when Eastman Kodak decided to shift from the ordinary 8 mm film to Super-8 mm. Many schools which had bought 8 mm film projectors found themselves with a useless projector on their hands. Having made an investment in 8 mm projectors they were in no mood to buy Super-8 projectors. This was felt particularly in developing countries. The cost of film loops which initially sold for about £5 when the early loops subsidized by the National Science Foundation came out, have now gone up to £11 and in some cases £17 per four-minute silent loop.

The promise of new low-cost technologies using cassette-TV and even disc-TV is keeping manufacturers from producing more loops and potential buyers from buying existing loops and projectors.

More will be said about these emerging technologies in the television section for it is conceivable that the film industry will be revolutionized by electronic techniques for shooting, storing and reproducing motion picture images.

We are suffering from the 'hardware-software syndrome'. Tremendous amounts of money are being poured into the invention of new hardware for the storage and display of motion picture images, but essentially no money at all is being spent on generating the physics education software that will be needed when the dust settles on the present controversy over what form the new audio-visual technology will take. This is probably the most important challenge: to plan the software now to be used when the new hardware is ready. One way to do this is to shoot films using the best existing conventional equipment to be transferred later for use with the new hardware.

6.4 MULTI-MEDIA AND AUDIO-TUTORIAL SCHEMES

The term 'multi-media' will be used here when a variety of media and materials (e.g. tapes, slides, films, specimens, laboratory kits, programmed texts, assignment sheets, etc.) are made available to the student predominantly in an *independent study* situation although the emphasis will be on the *integration* of the media rather than on *individualized instruction* which is covered in chapter 7. The media may include radio and television provided they are also integrated into the learning scheme. If the main emphasis is on broadcast radio or television it will be treated in the next section. Special emphasis will be given to the kind of multi-media system called *audio-tutorial.*

The *Survey of Literature* reveals very few physics multi-media projects. The topics are listed in Appendix 3.

The main exponent of the audio-tutorial approach to learning has been Postlethwait of Purdue [2]. His basic manual has examples mainly drawn from biology, but the techniques are applicable to physics. The title is *The Audio-tutorial Approach to Learning Through Independent Study and Integrated Experiences*. He says:

> "Emphasis on student learning rather than on mechanisms of teaching is the basis of the audio-tutorial approach. It involves the teacher identifying as clearly as possible those responses, attitudes, concepts, ideas and manipulatory skills to be achieved by the student and then designing a multi-faceted, multi-sensory approach which will enable the student to direct his own activities to attain these objectives. The programme of learning is organized in such a way that the students can proceed at their own pace, filling the gaps in their background information and omitting the portions of the programme which they have covered at some previous time. It makes use of every educational device available and attempts to align the exposure to these learning experiences in a sequence which will be most effective and efficient. The kind, number and nature of devices involved will be dependent on the nature of the subject matter under consideration.
>
> "In the audio-tutorial system the instructor's voice is available to the student to direct and supplement his effort. This does not mean that a tape lecture is given!! It refers to an audio-programme of learning experiences logically sequenced to provide information for skilled learning. The overall set of integrated experiences includes lectures, reading of text, or other appropriate material, making observations on demonstration set-ups, doing experiments, watching movies and/or any other appropriate activities helpful in understanding the subject matter."

Concerning multi-media systems which are not of the audio-tutorial type, the best example is probably that of the Open University in the United Kingdom. It is discussed in the article entitled: *Integrated multi-media systems for science education which achieve a wide territorial coverage* [2]. This article discusses several other projects, but again, the main thrust is on the instructional system of the Open University which utilizes in its physics courses printed course units written for self-study with built-in systems of assessment and home laboratory kits. It also utilizes radio and television but only for about ten per cent of the student's time for any given course. Space does not permit a full discussion of the Open University here, but the interested reader is referred to this article as an excellent introduction to this particular type of multi-media system. No other university leans so heavily on the concepts of educational technology in the planning of its courses.

We could, of course, have included the PSSC course and Project Physics of Harvard as early examples of courses that utilize several media. But they were not self-paced and self-instructional to the extent that the audio-tutorial and the Open University schemes are. The Unesco Physics Pilot Project in Latin America [25] pioneered a step in this new direction. It was a multi-media course and it was student-paced through a programmed learning technique.

Berman [4] has introduced a multi-media system for physics instruction which leans heavily on the combination of overhead projector and audio-tapes, but it is not audio-tutorial. The tapes have lectures on them and the course depends on seminar discussions. Baez devised a concentrated media-activated physics course of this type and experimented with it for five consecutive summers at Harvard University [5].

6.4.1 Problems and Challenges

The main problem with schemes discussed in this section is the difficulty of producing high quality 'software' to feed into the excellent hardware which already exists in the media. This requires experienced personnel, time and money, all of which are in short supply. Postlethwait estimates that it takes about 100–500 man hours to produce one multi-media unit (about a week's student contact time) from inception to final product. The production of the 36 units of the Science Foundation Course of the Open University involved some 12–16 academic staff plus technical staff including those of the Institute of Educational Technology and the BBC, typists, artists and laboratory technicians working for at least one year. No wonder Keller, experimenting with his personalized system of instruction (PSI) in Brazil where the financial resources available were not as great as those in the U.K., felt that he could not afford the 'frills' of multi-media approaches.

The challenge is to find applications of the multi-media approach which are *not* frills but which *are* appropriate to the state of economic, social and educational development of the country where it is to be used.

6.5 RADIO AND TELEVISION

Radio and television have been widely used in education in general and even in the teaching of science, but articles that deal with the teaching of physics are few in number. It is not possible to review here the vast literature of the use of radio and television in education, but the reader who wishes to obtain an introduction to this field could begin by consulting *Learning by Television* [6] produced for the Fund for the Advancement of Education. The first chapter, entitled 'The Unfinished Experiment' begins:

> "After more than a decade of extensive effort and the expenditure of hundreds of millions of dollars has television made a real impact on American schools and colleges? Has it made a worthwhile contribution to education?
>
> "The short answer to such a sweeping question would probably have to be 'no'. Whether measured by the numbers of students affected or by the quality of the product or by the

advancement of learning, televised teaching is still in the rudimentary stages of development. The medium can take credit for helping understaffed schools to cope with ever increasing enrollments. But television has not transformed education, nor has it significantly improved the learning of most students. In short, TV is still far from fulfilling its obvious promise. Television is *in* education all right, but it is still not *of* education."

Although this was written about educational television in the United States in 1966, it still applies to most of the teaching of physics by TV today.

Details of the use of radio and television in physics education in various countries are given in the references listed in Appendix 4.

For someone just becoming interested in the possibilities of radio and television in physics education a good source of information with good bibliographies is Unesco's *New Trends in the Utilization of Educational Technology for Science Education* [2]. In particular Valerien's article: 'The Use of Television in Science Teaching'; Berman's article: 'Learning Media'; and, of course, the article by Kaye and Pentz: 'Integrated multi-media Systems for Science Education which achieve a Wide Territorial Coverage'.

No mention has yet been made of the tremendous efforts made in connexion with television teaching of physics by Harvey White on Continental Classroom in the 1960's. He deserves credit for pioneering in a difficult field. It was a 'brave and costly experiment' but it was dropped after a few seasons without inspiring other courses of this kind. Less ambitious physics TV teaching experiments have been tried in other countries but none has achieved sufficiently resounding results to have generated successors.

6.5.1 Problems and Challenges

Why have radio and television failed to play an important role in physics education? One reason is that physics is a difficult subject and one which is not easy to teach even using conventional techniques, although many of its experimental aspects lend themselves to demonstrations which could make interesting TV programmes.

Another is that many TV science teaching programmes have been essentially ordinary lectures, recorded by the television camera. They were made with little appreciation of the special features inherent in the combination of films and TV. They simply had the TV camera 'look in' on the lecture room.

Too little attention has been given to the essential visual nature of the television medium. It is not surprising that attempts to convey verbal information by this medium have been unsuccessful.

In teaching, we have generally failed to profit from the example of the advertising industry who have so successfully used television as a means of motivating the viewer.

In other words, it is the 'software' problem again. Television technology has improved. The image quality has improved, colour has been added. Satellites have made it possible to reach a vast audience, but a similar effort in generating high quality software in the area of physics has simply not taken place. As we said earlier, the development of high quality software is now even more important than continued improvement of the hardware. But it is also important to recognise the characteristics of the improved hardware because it will be for these new and improved versions that the software of the future must be created.

One of the new directions is to supplement broadcast television with, or replace it by, other means of supplying the viewer with synchronized moving pictures and sound. One of these is cable television in which the information is guided selectively by carriers and is not broadcast through the air. Another is cassette or disc TV in which sight and sound are recorded electronically on magnetic tape, on a phonograph-like disc or in some other fashion. The important characteristic is that the viewer can insert the tape, disc, or other device and play it back on his own school or home television set *at the time of his choosing*, and replay it as many times as he wishes. There is a vast difference between the teaching possibilities associated with cassette or disc TV and those associated with broadcast television. Cassette TV (I shall use this as a generic term to mean any system in which the audio and visual signals are stored in devices which make instant and repeated replay possible at the discretion of the viewer) makes it possible to use a self-paced multi-media approach for physics teaching in which other learning devices are linked with TV in new teaching-learning strategies, such as programmed learning and the performance of experiments. It could yield a modification of Postlethwait's idea to become an 'audio-visual-tutorial' presentation with all the advantages of his audio-tutorial techniques combined with the visual display on the TV screen instead of through movies and slide projectors.

What is most needed in using television, as indeed in using other media, is to apply the four important parameters of programmed learning detailed earlier, namely:

a. Identification of the target population

b. Statement of the objectives

c. Selection of content

d. Selection of the appropriate medium and mode of delivery

If we follow this procedure it may well be that we are forced to conclude, in certain cases, that television – either broadcast or cassette – is *not* needed.

The choice of objectives also poses a problem. If we restrict ourselves to the teaching of physics at the university level for future physicists and engineers, we will be forced to consider a highly structured course which may be difficult if not impossible to teach using broadcast TV, but which might be feasible using cassette-TV as part of a multi-media self-paced system.

On the other hand, if the target population is the general audience that watches educational TV channels our objective might be to give them some idea of the power, methods, and limitations of physics without requiring a highly structured course. In this case broadcast TV might serve the purpose of generating a 'scientifically literate' public without requiring them to take an examination on Newtonian mechanics or quantum physics for example.

The use of broadcasts combined with printed or other visual materials (radiovision) has hardly been explored for physics teaching and deserves some consideration in developing countries since it is much cheaper than TV and, with good software, can be very effective.

In short, TV still holds out the unfulfilled promise of bringing physics instruction of high quality to a large target population but it must take into account both the improvements in TV technology (that is the new hardware and its capabilities) and the concept of educational technology which demands that target, objectives, content and mode of delivery be considered carefully in that order.

6.6 COMPUTERS IN PHYSICS EDUCATION

In spite of the fact that, judged by the number of bibliographical references, this is the most active area of research, development and experimentation in educational technology today, and partly because it *is* so active and hence difficult to cover in a limited space, this will be the shortest section of the present paper. Another reason is that the activity is highly concentrated in advanced countries, mostly because of the high cost of computers and the scarcity of adequately trained personnel. A study made by Unesco suggests that few existing materials can be adapted for use in developing countries and that their educational aims can, for the time being, probably be accomplished without computers.

The *Survey of Literature on Physics Education* had 68 entries dealing with computers in physics education: one from Italy, one from the UK and all the rest from the US. Notably absent are countries from the Third World, for a very simple reason: computer-assisted instruction is expensive and even its most enthusiastic practitioners warn that computer-aided instructional installation has to be at least of a minimal 'critical size' to pay off. Donald Bitzer and his colleagues say [2]: "the use of computers in direct instruction will be possible on a wide scale only if it is economically feasible, no matter how great the supposed benefits. Typical costs of educational computer systems have been about £2–£5 per student contact hour, which is good enough to hire a private tutor. A cost reduction of a factor of ten is required to make it feasible to use computers in education." We have included computers in the list of topics, therefore, because of their potential and their promise; *not* because they represent the appropriate technology for the majority of countries at present. See Appendix 5.

6.6.1 What the Computer can do in Physics Education

Computers are of two types, analogue and digital. In the analogue devices numbers are represented by physical quantities like length, angle or voltage. In the digital devices numbers are expressed as digits, usually in the binary system. An ordinary slide rule is an example of the analogue type and the electronic calculator is an example of the digital. Great strides have taken place in electronic digital computers so that the advantage of speed which used to rest with the analogue types is probably shifting to the digital types which, moreover, have readouts in the decimal system of great precision – too great for many teaching needs, according to some investigators. The hand calculator is a special electronic device which is of great utility in the teaching of physics; it is considered at length in chapter 11.

The following is a brief list of functions that computers of sufficient complexity can perform to help in physics education:

(a) *Mathematical analysis*. Computers can be programmed to solve even very difficult mathematical equations very rapidly, so rapidly in fact that they can, for example, track and guide rapidly moving objects in real time. Since most problems in physics are stated in mathematical form (e.g. in mechanics, wave motion, oscillating circuits, atomic and nuclear physics, etc.) their computational and problem-solving capabilities can be useful in physics education. Curves can be fitted by least squares analysis.

(b) *Graphical display*. The solution of a mathematical problem is often associated with a graph or diagram. The shape of a wave in electro-dynamics or nuclear physics, for example, or the density distribution of electrons in an atom, or the trajectory of a moving particle all lead to graphics which can be displayed on a cathode-ray tube screen or on plasma devices. These figures, if varying in time, can also be photographed on motion picture film and yield computer animated movies. Varying electric and magnetic fields can, for example, be plotted and filmed.

(c) *Experiments*. Through modelling, simulated experiments can be performed in which relevant variables (e.g. mass, speed, acceleration, time, density, tension, temperature, etc.) can be varied continuously by changing some electrical parameters. The numerical and/or graphical result of these experiments can be used by the student to learn, from many more cases than he could have access to with real experiments, how the variation of parameters affects the outcome of the experiment. Some of these simulations are a form of computer-animation. A model of a stretched spring, for example, can consist of a thousand small bodies linked by massless springs of a given stiffness. The programme consists in 'telling' the computer to move the bodies in accordance with Newton's Laws of Motion. If the body at one end is vibrated sinusoidally, for example, a wave that resembles a travelling sine wave is generated.

(d) *Computer-assisted learning.* One or more of the previous functions can be utilized to generate programmes which actually teach, or more precisely, from which students can learn. One procedure is the use of the computer to guide the student in programmed learning of either the linear or branching type. Another is to use the computer in an interactive mode, that is, one in which a dialogue is set up between the student and the computer. This can even be tied in with graphic displays which are subject to interactive change initiated by the student who wants to know how this particular change affects the outcome of an experiment.

For the reader who is new to these concepts, the article by Bitzer [2] is recommended as a start. It contains a good bibliography. Some general references are given at the end of this paper as well as some related to physics education in particular.

There has been so much activity in the use of computers in physics instruction in the United States that the reader who wants details should go directly to the index issues (December) of the *American Journal of Physics* starting with the latest and working backward. They are listed under the topic: 'Instructional Computer Use and Computer Notes'.

(e) *Computer management of learning.* The computer can be used in many ways to help manage the learning situation. Here the computer is not the main instrument of instruction as it is in computer-assisted learning. It is used instead for the storage of questions and the generation of tests with specified characteristics. It can also be used to mark and analyse test results, and to direct students to remedial material. Records can be stored for assessment and evaluation of student performance. Individual reports can be produced for each student, showing his or her results to date.

6.6.2 Problems and Challenges

The main obstacle to the use of computers in physics teaching is probably the high cost of installation of a computer of at least the minimum critical size. Computers *are* expensive if we require that the student interacts directly with the machine, as is the case when computer terminals are to be available on site. However if batch-processing methods are applied to the computer management of learning, and if a one- or two-day turn-round is acceptable, then the cost per student can be relatively small.

The 'software' problem is probably just as urgent in the area of computer-assisted instruction as it is in other areas covered in this chapter. The rate of development of the technology of computers is probably outstripping the rate of production of good programmes for them. The solution of this will probably require massive funding by centralized agencies of science and education within the different countries.

The possibility of international collaboration in the development of computer-assisted physics instruction is a challenge that may be met in part through the efforts of the Specialized Agencies of the United Nations, particularly Unesco.

6.7 SUGGESTIONS FOR ACTION

Keeping in mind the disparity in resources available to different countries, suggestions for action are listed in two groups:

A. For developing countries and for the economically depressed sectors of others.

   (i) Read the literature. The bibliography contains some suggestions on how to get started.

   (ii) Consider systems such as the Keller Plan that require almost no hardware, other than that required for laboratory practical work. Then explore the opportunities for enrichment and improvement of learning provided by the newer 'things of learning', but not at the expense of experiments performed by the student.

   (iii) Start modestly and work up. Learn the basic arts of audio-visual communication by experimenting with, say, slides, overhead projectors, audio-tapes, 8 mm films, 16 mm sound films, closed-circuit TV, radiovision, broadcast TV in that order. Think twice before jumping into the use of computer-assisted instruction.

   (iv) Get teachers and students involved in the development of software for physics teaching. The level of awareness and receptivity of large numbers of them must be raised by becoming involved creatively.

B. For the economically advanced countries.

   (i) Make a conscious effort to devote substantial resources to generating software of high quality for the existing technological hardware and for that which is on the verge of commercial mass-production such as cassette or disc TV.

   (ii) Do research and development in areas which would have some benefit in your own economically depressed areas and hence in the developing countries.

   (iii) Assist the United Nations and other agencies in programmes to stimulate international collaboration in the field of educational technology.

   (iv) Consider the suggestions made to developing countries to see which are also applicable to your own.

6.8 APPENDICES

Appendix 1

Examples of programmed learning utilized in physics education in various countries.

Australia:	Evaluation of a group controlled audio-visual system of programmed learning [7].
Chile:	Functional and behavioural objectives in the teaching of science (examples from physics) and educational technology in science teaching [8]; relation between evaluation and learning objectives [9].
Czechoslovakia:	Statistical evolution of the didactic tests in physics [10].
France:	Comparative study on the use of books and machines in programmed instruction of electricity [11].
Hungary:	The programmed teaching of electricity [12]; the entrance manual of physics (programmed) [13].

Italy:	Trials of programmed instruction with closed-circuit television [14]; an experiment on programmed instruction [15]; the "packages" for the teaching of physics [16]; the construction of programmed sequences in physics [17].
Poland:	Method and examples of didactic programming [18] and attempt at programmed teaching in geometrical optics [19].
Romania:	Programmed instruction in physics classes [20].
United Kingdom:	The physics interface project (self-teaching modules) [21].
United States:	Programmed course in mathematics necessary for success in collegiate physical science [22]; the effects of programmed instruction in a college physical science course for non-science majors [23].
Japan:	Media programmed learning systems [24].

Unesco ran a pilot project on the teaching of physics in Latin America starting in 1963 in which programmed learning materials were produced by the participants [25]. It was probably the pioneer programmed learning project in that region. E.W. Hamburger in a survey of the situation in Brazil, mentioned that a programmed learning text in five volumes covering most of classical physics has recently been produced by a private group in Brazil under the title *Fisica Auto Instrutiva* and that about 150,000 volumes have been sold. It contains recommendations for experiments but these are not an indispensable part of the course. Harvard Project Physics also integrated some programmed learning sequences into its materials. Programmed learning has also been utilized in Chile to train teachers by correspondence.

Appendix 2

Examples of audio-visual aids utilized in physics education in various countries.

Australia:	Recent application of the use of tape recorders in tertiary science teaching [26].
United States:	Students answer questions flashed on screen [27]; evaluation of use of tapes, 35 mm slides and printed materials [28]; audio-visual aids for astronomy and space physics [29]; preview of slides, film loops and video-tapes and use of microcomputers as adjuncts to laboratory experience [30]; the influence of selected Physics Science Study Committee (PSSC) films [31]; the Harvard project physics film programme [32]; a long look at the short film [33]; and the enquiry approach in 16 mm sound films [34].
France:	A selection of films suitable for the teaching of physics [35] and Animation in physical science films [36].

Here are some miscellaneous items regarding film activities. Lewis [37] has reported on the use of films in the teaching of physics in the USSR. He wrote (in 1961) "in the Ukrainian Republic there were one hundred pre-O-level films, in the Russian Republic 144, which must be shown to the pupils. Most of them were short but all were pertinent to the subject. We have almost no such films". When Baez visited the USSR in the late 1960's he was shown examples of the use of films in the teaching of physics in Moscow. Their present extensive efforts in educational television suggest that a corresponding film and kinescope activity must be under way [38].

E.W. Hamburger (Instituto de Fisica de Universidade de Sao Paulo, Departemento de Fisica Experimental) reports that "short silent film-loops for introductory physics have been produced on the themes 'Centre of Mass' (6 films) and 'Collisions' (6 films). Careful tests of the teaching effectiveness of the films were carried out". He also adds "Films (were) produced by C. Jonas in collaboration with FUNBEC on several topics (energy, forces, etc.) at the introductory level. (They are) coloured ten-minute sound films available in 35 mm and 16 mm and they are very attractive and good teaching tools. There are ten films in all".

J.B. van der Kooi (Groningen University, the Netherlands) reports that three films for in-service training have been produced, covering experiments with electromagnetic 3cm waves. In addition students at that university have been given the opportunity of making their own educational films; six films so far have been made and the project is continuing.

Appendix 3

Audio-tutorial and multi-media projects in physics education.

(a) *Audio-tutorial*

Australia:	An audio-tutorial project in physics [39].
United States:	A practical approach to an audio-tutorial system [40]; how to develop and use audio-tutorial instruction in secondary school science [41]; an inexpensive audio-tutorial system [42]; the use of audio-tutorial methods in introductory physics at Cornell University [43].

(b) *Multi-media*

Italy:	A teaching experiment of the multi-media type [44].
United States:	A high school physics course that makes use of a multi-media approach [45]; a multi-media facilitated course in college physical science [46]; multi-media systems approach in college physics laboratories [47]; formative evaluation procedures used in designing a multi-media physics course [48].

Selected readings

Briggs, L.J. et al. *Instructional media: a procedure for the design of multi-media instruction, a critical review of research and suggestion for future research.* Pittsburgh, American Institutes for Research, 1967.

Contains a useful review of the literature on audio-visual media (up to 1965), and a select bibliography.

Duncan, C.J. *A survey of A V equipment and methods.* In: D. Unwin *Media and Methods,* London, McGraw-Hill, 1969.

"There is a constantly shifting interaction between the equipment on a technical level and the materials and methodology applied at the professional teaching level". "A desire for simplicity, if not for ease, may well hold back an experienced teacher from using any aids he has not already made second nature". ". . . an element of conscious programming is proper to the selection and use of even the most simple aids, let alone their association in complex systems". Famous cases of combined AV labs are those at Purdue and Pennsylvania State universities. "The more complex the aid, . . . the less sensitive the adjustment to individual or single-class needs and responses".

Romiszowski, A.J. *The selection and use of teaching aids,* London, Kogan Page, 1968.

A practical handbook on the use of new devices and media in the classroom, and for self-instruction.

Unwin, Derick, ed. *Media and methods: Instructional technology in higher education,* London McGraw-Hill, 1969.

Developments considered by the editor to promise well for the future are CAI, Dial-Access Information systems, and Simulation and Gaming. Used as a teaching machine, the computer can impose some control in programmed learning (used at Santa Monica, California). The system includes a manually operated microfilm viewer and a response device connected to the computer, the latter indicating correct responses by a green light and incorrect ones by a red light. Consoles are provided enabling teachers to monitor progress. Other systems include PLATO, SOCRATES and COURSEWRITER. Ordinary telephone lines can be used for remote connexions. Useful boundaries for 'simulation and gaming' are not easy to define, but devices such as ripple-tanks and wind-tunnels are included.

Driver, S.C. *'Programmed individual study methods in the learning of science'.* Australian Science Teachers' Journal, May 1970, vol. 16, no. 1, p. 27–33.

Deals largely with activities at the University of Melbourne, in biology, physiology, biological chemistry (3rd year) and biochemistry. Though based on Postlethwait's methods, the term 'audio-tutorial' is not used, as it is considered unduly restrictive, the 'programmed' aspect is highlighted instead. The contrast with programmed ETV is pointed up: in that system the student is locked into step. The term 'structured' learning is introduced as synonymous with 'programmed' learning. The taped commentary must be prepared as a talk to an individual rather than as a lecture to a class.

Appendix 4

Radio and television in physics education.

New forms of paedagogical practice in physics [45]; application of closed circuit TV during physics lessons [50]; use of video-tape in advanced physics laboratory [51]; the report of a failure in biology teaching [52]; ten years of TV teaching [53]; the use of portable video-tape recorders in science education [54]; using television as an effective tool in science education [55]; science education by radio in Africa [56]; broadcasting and the teaching of science in secondary schools [57].

Selected readings

Schramm, Wilbur. 'The future of educational radio and TV'. *Educ. TV internat.* December 1970, vol. 4, p. 282–6.

More than 50 countries now have school TV and more than 100 have some educational TV. The problem is how to improve programmes, which means concentrating talent at a central point, without interfering with local control of timetable. One solution might be a wired network enabling desired programmes to be called up (example: Palo Alto students in maths connected to computer at Stanford University). Educational TV may merge into point-to-point transmission; satellites will play an important part. The time for incubation of the great changes envisaged may be '25 years in the industrialized countries, 50 years or more in the developing countries'. Little is known about how to combine PI with radio and TV effectively. Information centres for providing information on educational TV and radio would be extremely valuable. Radio can perform almost the same tasks as TV at one-fifth the cost.

Gordon, George N. *Classroom television. New frontiers ITV.* New York, Hastings House, 1970.

A survey of 20 years development of instructional TV leads to the conclusion that classroom TV is little more advanced or accepted than in 1950. Video-tapes are likely to replace broadcasts. Discusses the varieties of teaching and learning possible with TV, including CCTV, and describes the process of integrating TV lessons into the classroom curriculum.

Packham, D., Cleary, A. and Myes, T. (eds.). *Aspects of Education Technology V*, London, Pitman, 1971.

Collected papers presented at the fifth Conference of the Association for Programmed Learning and Educational Technology.

Internationales Zentralinstitut for das Jugend und Bildungsfernsehen – a bibliography, Munich, 1968.

University of Sussex. *Television and education: research findings, bibliographies, and sources of information* – a report to the E.V.R. partnership. University of Sussex, Centre for Educational Technology, 1968.

A detailed report which reviews the present (1968) state of research on educational television, sets the findings in the context of British educational practice, and gives a select bibliography of relevant research, material, and sources.

Beaton, W.G. 'Glasgow ETV – a quinquennial report'. *Education and training,* November 1970, p. 436–7.

A brief account of the growth of the Glasgow ETV service from its start in August 1965. Emphasis is on the hardware aspects, but mention is made of programmes in modern mathematics for secondary pupils and of biology programmes produced by the university and transmitted after school hours as in-service training for teachers. The budget figures up to 1970 'would seem to suggest that Glasgow Educational Committee believes with us that the interesting but expensive TV experiment of 5 years ago is proving to be a sound, long-term educational investment'.

Chaplin, Brian. 'Educational radio and the use of the tape recorder'. *Educational Broadcasting International,* June 1971, vol. 5, no. 2, p. 107–12.

Emphasises the benefits to be derived by taping broadcast programmes, thus making material available just when required. As regards 'Radiovision', 'investigations in Toronto to measure the assimilation of information by TV, radio, lecture and textbook, found that the textbook was the least effective, with the lecture only marginally better. Surprisingly, radio supported by visual material was significantly better than TV (though the latter proved superior in stimulating interest and heightening motivation). The tapes can of course also be used for individual revision.

Chittock, John. 'TV Cassettes – Friend or foe?' *Educational Broadcasting International,* September 1971, vol. 5, no. 3, p. 164–7.

Consideration is confined to systems with electronic reproduction (on a TV screen), which are recognised as being more versatile than optical reproduction systems. EVR, Teldec discs, VTR tapes, Telecine, Selectavision (using lasers and holography) and other systems are compared. Expense alone may inhibit the use of cassettes in education, though it may be feasible in conjunction with existing centralized CCTV systems.

Appendix 5

Computers in Physics Education: Selected Readings

Gerard, R.W., Hilgard, E.R., Atkinson, R., Goodlad, J.I. *Symposium on computer assisted learning.* Proceedings of the National Academy of Sciences. Washington, vol. 63, no. 3, July 1969, p. 573–603.

Contains four articles whose titles are: (1) Computer-assisted learning and general considerations, (2) The psychological heuristics of learning, (3) Computer-assisted learning in action, and (4) Computers in the schools in modern society. Contains valuable insights on the capabilities of computer-assisted instruction and is useful even though a bit dated in this rapidly growing field.

Daniels, A. (ed). *Educational Yearbook 1971–72,* The British Computer Society, London.

A collection of recent articles, review, and project listings (UK and USA).

Hickey, Albert E. *Computer-assisted instruction: a survey of the literature.* Newburyport, Mass., Entelek, 3rd edn. 1968.

A formal bibliography of some 600 items preceded by the survey, which highlights: specific applications of CAI in various disciplines (including maths and sciences) and at various levels, the major CAI centres in the US (and a few in other countries) the most important CAI systems, programming languages, and modes of instruction.

Zinn, K.L. and McLintock, S. *A guide to the literature and interactive use of computers for instruction* (2nd edn.) Stanford, ERIC Clearinghouse on Media and Technology, 1970.

A useful guide – includes sytems and language descriptions, literature surveys, relevant professional organizations, bibliography, etc.

Kemeny, John G. and Kurtz, Thomas E. *The Dartmouth time-sharing computing system – final report,* Hanover, Dartmouth College 1967, 24p.

Commission on College Physics, *The computer in physics instruction,* College Park, University of Maryland, 1965, ix 80p. flow chart.

Schwartz, Gunter, Kromhout, Ora M. and Edwards, Steve. *'Computers in physics instruction', Physics Today,* September 1969, vol. 22, no. 9, p. 40–49.

Early research on the use of computers in science education was conducted at the Universities of Michigan and Illinois. Conferences were held in 1965 at Universities of Washington and California, Irvine. A recent survey indicated that computers are finding many applications, functioning in a few fundamental roles. It is hoped eventually to attain a cost as low as 25 cent/hour/student. The three main modes are: computational, conversational, simulation. A tabulation of 27 representative 3rd level CAI physics projects is given. But this does not cover use of small computers (e.g. IBM-1130), which may however be best for many schools. Easy access and simple computer language are important factors. 40 references.

Computers in Physics Education: Further Reading

Adolfsson, T. *Laromedelskonstruktion – Lagersrapport* No. 1, 1971 and No. 2, 1973. The Swedish project TRUAS is briefly described.

Council for Educational Technology. *Computer assisted learning in the UK* 1975.

A 'state of the art' report with a case study approach so that the reader will get some detailed understanding of particular work as well as more general information.

Can be obtained on application to the CET, 10 Queen Anne Street, London W1M 9LD.

Council for Educational Technology. *Two Years On.* 1975.

First report of the National Development Programme on computer-assisted learning in the UK.

Can be obtained on application to the CET, 10 Queen Anne Street, London W1M 9LD.

Brok, Alfred. *Current Status of the Physics Computer Development Project.* Department of Physics University of California, Irvine, California 92664.

Elton, L.R.B. *The Interplay of Educational Technology and the Teaching and Learning of University Physics.* Institute for Educational Technology, University of Surrey, Guildford, England.

Ameloot, P., Beerden, L., Poulis, J., Venhaegen, L. *Audio-cassettes are an aid to Problem Solving in Physics.* Limburgs Universitair Centrum, Universitaire Campus, 3610 Diespenbeek, Belgium.

Van der Kooi, J.B. and Mulder, D.P. *Films for in-service Training and Student-made Films for High Schools.* Groningen University, The Netherlands.

The CAMOL project (Computer Assisted Management of Learning).
Writer: N.J. Rushby, NDPCAL, 37–41 Mortimer Street, London W1N 7RJ.

6.9 REFERENCES

1. International Conference on Physics Education: *Survey of Literature on Physics Education.* Edinburgh, Physics Department, University of Edinburgh, 1975.

   Contains general references plus others from 20 different countries on all the subjects covered at the conference.

2. *New trends in the utilization of educational technology for science education,* Paris, Unesco, 1973.

   Chapters on computer based science education, programmed learning in science education, the use of television in science teaching, the use of radio in science education, learning media selection and utilization in science education, integrated multi-media systems for science education which achieve a wide territorial coverage, integrated multi-media systems for science education, educational technology in the training of science teachers and educational technology applied to the learning of science in developing countries.

3. *Teaching School Physics* Editor John L. Lewis. Penguin, Harmondsworth, U.K. 1972.

   A Unesco source book on the teaching of physics at the secondary level, produced in association with the Teaching Commission of the International Union of Pure and Applied Physics.

4. Berman, Arthur I. and Baez, Albert V. *Seminar/Autolecture Experiences.* Am. J. Phys. *38*, 313 (1970).

   Describes a four-component class instruction method utilizing; autolecture (overhead projector and table-top recorder presentation run by a graduate student monitor including pauses for answers to posed questions), seminar (with the instructor who answers anonymous questions raised during autolecture and poses questions to be answered by students on NCR forms – correct answer given after one copy handed in), micronotes (exact reduced copy of autolecture transparencies), autograding (described under seminar). Results of use in four locations is summarized. [See Baez, Am. J. Phys. *41*, 1266 (1973).]

5. Baez, Albert V. *Evolution of a Concentrated, Media-activated Physics Course.* Am. J. Phys. *41*, 1266 (1973).

   Describes "a teaching-learning strategy based on the use of the overhead projector, the tape recorder, film loops, and closed circuit TV in autolectures, seminars, micronotes, laboratory sessons with multiple options, and demonstration lectures". The course was taught to approximately 100 students, lasted six and one-half weeks, and was given at the Harvard summer school from 1967–71.

6. Murphy, J. and Gross, R. *Learning by Television,* New York, The Fund for the Advancement of Education, 1966, 95p.

7. Le Marne, A.E. (1972). Evaluation of a group controlled audio-visual system of programmed learning. *Physics Education,* 7, 218.

8. Boletin de Educación. Educational Bulletin of Unesco's Regional Office of Education, Santiago, Chile. Articles are:--

   (1) Gaudet, G.G. "Objetivos funcionales y operacionales en la enseñanza de las ciencias" (Functional and behavioural objectives in the teaching of science.) Discusses, with examples of physics, the need for clear objectives in science teaching.

   (2) Dib, C.Z. "Tecnología de la educación y enseñanza de la ciencia" (Educational technology and science teaching). Briefly describes the principles and foundations of educational technology and ways to use it in the development of learning systems.

   (3) González, C. "El equipo y el laboratorio en la enseñanza de las ciencias". (Equipment and laboratories in science teaching). Discusses educational goals which may be attained through the use of apparatus in demonstrations and experiments.

   (4) Maiztegui, A.P. "Las actividades científicas extraescolares". (Out of school scientific activities). Analyses various out of school activities and their possible educational value.

   (5) Teixeira, A.S. "La evaluación en la enseñanza de la ciencia". (Evaluation in science teaching). Describes how to construct, analyse and evaluate examinations in science.

   (6) Dodera, O. 'Formación y actualización del profesor de ciencias". (Pre-service and in-service training of science teachers). Analyses desirable attributes of a teacher in the sciences and ways to provide them.

9. Magendzo, A. "Relación interna de evaluación-objetivos de aprendizaje". (Relation between evaluation and learning objectives). Boletin Informativo del Departamento de Física No. 3, 28, 1974.

   Through worked examples in physics, discusses the influence of behavioural objectives on evaluation procedures.

10. Bednãrik, M. "Statistical Evolution of the Didactic Tests in Physics in Collected Reports of the Faculty of Natural Sciences", Palacký University, Olomouc, Acta Universitatis Palackianae Olomoucensis, Mathemetica-Physics-Chemia X, 1969.

    The article deals with the statistical calculation of the results of didactic research conducted between 1966 and 1967. The aim was to prove the effectiveness of programmed learning for specific topics of physics. Testing knowledge in two selected groups at random, the author provides relevant comparative data. The results show that differences in pupils' knowledge after having studied the subject matter prove the advantage of experimental learning.

11. Freiche, J., Higele, P. *Etude comparative de l'emploi de livres et de machines dans un enseignment programmé de'électricité.*

    Philips machines of the EL9000/00 type provided a programme in elementary electricity for the group selected. The impact of the machine was examined in several respects:

    - effectiveness of learning;
    - changes in the adult's image of training;
    - quality of the periodical syntheses carried out by the group undergoing training.

12. Lang, J., Dios, J. The programmed teaching of electricity. Fiz. Tan. 8, 59–61, 1969.

    The authors deal with the characteristics of programmed teaching and the pupils' experiments. A programmed lesson on diodes is discussed in detail. Lastly, they examine the knowledge gained by the programmed method.

13. Schuszter, F. The entrance manual of physics. Research Centre of Higher Education, Budapest, 1973, p. 113.

    This is a programmed handbook, similar to the Orear programme for preparing for the entrance examination of colleges and universities.

14. Bussolati-Rimini. Esperimenti di istruzione programmata con televisione a circuito chiuso, in relazione alla realizzazione di corsi universitari. Il Giornale di Fisica 12, 124, 1971.

    (Trials of Programmed Instruction with closed circuit television, for the preparation of university courses). An analysis of the production of a Programmed Instruction course, recorded on a television tape and operated with three or four student groups. The project has been sponsored by the Pirelli S.p.A. The programme was of the Skinner (linear) type. The cost of production has been estimated at 400.000 L for one hour lecture.

15. Moltedo, Pani. Un esperimento di insegnamento programmato. Il Giornale di Fisica 11, 131, 1970.

    (An experiment on programmed instruction). Reports on a programmed course in electrostatics, at secondary level.

16. Pescetti. L'impiego dei "pacchetti" nell'insegnamento della fisica. La Fisica nelle scuola, V, N.1, 11, 1972.

    (The use of "packages" for the teaching of physics). A report on a study and the consequent preparation, at Geneva university, of "teaching packages" on light polarization (the material consists of programmed instruction sheets, tests, problems, experiments, etc.).

17. Scarpellini. I teorici dell'Istruzione programmata: Skinner Audiovisivi, XI, 3, 51 (1971).

    I teorici dell'Istruzione programmata: Crowder Audiovisivi, XI, 4, 31, (1971).

    Come costruire un programma Audiovisivi, XI, 5, 14, (1971).

    Come costruire una sequenza lineare Audiovisivi, XI, 6, 23, (1971).

    Come costruire una sequenza intrinseca Audiovisivi, XI, 7, 14, (1971).

    This is a series of papers containing information and directions for the construction of programmed sequences in physics.

18. CZ. Kupisiewicz (edit.) Metody i przykady programowania dydaktycznego, Warszawa 1970, PWN.

    Methods and examples of didactic programming.

19. Salach, J. Próba programowego nauczania optyki geometrycznej. Fizyka w Szkole, nr 6, 1967.

    An attempt to programme the teaching of geometrical optics.

20. Muster, D., Chiritescu, S., Corutiu, M. and Tirca, L.D. Lectii cu elemente de învat̀amint programat în fizica; Revista de pedagogie *22* (5) 1973.

    Programmed instruction in physics classes.

21. Sutton, R.A. "The School-University Physics Interface Project". Physics Education, vol. 7, p. 212, May 1972.

    Pre-course diagnostic tests for students starting university physics courses are proposed. Students can then use self teaching modules to remedy deficiencies inherited from A-level courses.

22. Colligan, Robert B. "The Construction and Evaluation of a Programmed Course in Mathematics Necessary for Success in Collegiate Physical Science". J. Res. Sci. Teach. *6,* 358 (1969).

    Experimental and control groups of students with poor mathematics background (77 students in each group) were given programmed remedial material in mathematics and a lecture-recitation course in mathematics, respectively. The experimental group did significantly better both in the mastery of mathematics and also in a subsequent physical science course.

23. Moriber, Dr. George. "The Effects of Programmed Instruction in a College Physical Science Course for Non-science Majors". J. Res. Sci. Teach. *6,* 214 (1969).

    A three-week portion of a college physical science course was prepared in linear programmed form and used with 120 students, while 120 other students were taught by the regular lecture-demonstration method. The immediate acquisition of knowledge was greater for those students using programmed learning, but retention after three months was the same for both groups.

24. Butler, Lucius; and Inoue, Kazuo. "Media Programmed Learning Systems". Phys. Teach. *10,* 20 (1972).

    Describes an "integrated media programmed learning system" offered to first- and second-year high school students in Kobe, Japan. Individual multi-media learning activities for a one-or-more week unit take place between an initial and a final large-group presentation. Students participate in selection of learning materials and keep their own records.

25. *Unesco Pilot Project on the Teaching of Physics – Report on this project Unesco,* Paris, 1967.

    This is a report (80 pages plus illustrations) on a project sponsored by Unesco and IBECC, and held in Sao Paulo (Brazil). About 25 Latin-American physicists and physics educators worked for a year with a Unesco team on the design of a course on the "Physics of Light" as part of a secondary-level physics course. They produced a coherent set of materials including laboratory kits, pupils' textbooks (in programmed instruction form), films and TV programmes. The textbooks, which were originally produced in Spanish and Portugese, are at present commercially available in Spanish, English and French versions also exist (in a limited experimental edition).

26. Daley, N.J. and Gore, M. M. (1970). Recent applications of the use of tape recorders in tertiary science teaching, *Aust. Physicist,* 7, 83.

27. Meinhold, Russel. *Large Group Instruction Through Concept Development. Final Report.* (DHEW Report BR-8-A-042) (1970) ED 063 266.

    Format based on class sessions centred on single concepts. Written materials, demonstrations, students answer questions flashed on screen concerning concept. Format evaluated: Found to be more "interesting" than straight lecture format.

28. Yoder, John T. III. *Development and Evaluation of Instructional Aids in a Technical Physics Course for Industrial Technology Students. Final Report* (1969) (DHEW Report: BR-8-F-062) ED 031 415.

    Evaluation of use of audio-tapes, 35 mm slides and printed materials.

29. Moche, Dinah L. "Audiovisual Aids for Astronomy and Space Physics at an Urban College". Phys. Teach. *11,* 409 (1973).

    A commentary on, and listing of, easily-available audiovisual aids for astronomy courses, some of them useful at several instructional levels.

30. Reid, W.M. and Arsenau, D.F. "Labs of Unlimited Scope". Am. J. Phys. *39,* 271 (1971).

    Misleading title: article describes preview of slides, film loops, and videotapes and use of mini-computers as adjuncts to laboratory experience. Four examples given. Open-ended nature of experiments asserted but not described. No evaluation.

31. Woodman, Charles A. "The Influence of Selected Physical Science Study Committee (PSSC) Films on Certain Learning Outcomes in the Teaching of High School Physics". J. Res. Sci. Teach. *9,* 271 (1972).

    A test using approximately 500 students taking PSSC physics in eastern Massachusetts, USA, high schools showed that those who watched selected PSSC films did not have significantly different scores from those who did not watch the films, as measured by PSSC achievement tests and the Test on Understanding Science. Suggests that teachers might use films to stimulate student interest to break up class monotony, to supplement lab work, or to increase the range and scope of the course.

32. Bork, Alfred M. "The Harvard Project Physics Film Programme". Phys. Teach. *8,* 163 (1970).

    Describes three long films and lists a large number of short film loops developed for the high school course Harvard Project Physics (HPP). The "library" character of film loop use is described. Many HPP loops suggest and allow for student measurements and calculations.

33. Miller, Franklin, Jr. "A Long Look at the Short Film". Am. J. Phys. *39,* 4 (1971).

    Uses for the short film, legitimate reasons for producing one, variety of projectors available, need for more teachers to make short films.

34. Herbert, Don. "The Inquiry Approach in 16 mm Sound Films". Sci. Teach. *38,* 39 (March 1971).

    The Mr. Wizard of USA-TV fame describes some inquiry-slanted techniques of filming science demonstrations.

35. Flechon, J. Présentation d'un choix de films pour l'enseignment de la physique. IN: Bulletin de l'Union des Physiciens, No. 533, March 1971, p. 663–687.

    A selection of films suitable for secondary school physics courses.

36. Roger, C. *Le dessin animé et le film de sciences physiques.* Saint-Cloud, C.A.V., 1971, 50p bibliography (Memoire de stage).

37. Lewis, J.L. Education in the USSR with particular reference to physics; *Bulletin of the Institute of Physics and the Physical Society.* July 1961, p. 189–196.

38. Shaffer, Melvin C. Educational television in the Soviet Union *Audio-visual Instruction,* vol. 15, no. 3, March 1970, p. 69–73.

39. Hanscomb, J.R. and Arbib, P.S. (1971) An audio-tutorial project in physics. *Aust. Physicist, 8,* 173.

40. Nordland, Floyd, Kahle, Jane and Hugh, Via. "A Practical Approach to an Audio-Tutorial System". Sch. Sci. Math. *72,* 673 (1972).

Questions and answers about the practical problems in setting up a high school or university audio-tutorial centre.

41. Butzow, John W. and Pare, Roland. "How to Develop and Use Audio-Tutorial Instruction in Secondary School Science". Sch. Sci. Math. *73,* 735 (1973).

A brief "how-to-do-it" paper including references and bibliography to research results, kinds of audio-tutorial programmes, costs, hardware, procedures for writing materials. The authors stress that the teachers in each school must make their own basic audio-tutorial materials, and give reasons why this is so.

42. Sandin, T.R. "An Inexpensive Audio-Tutorial System". Phys. Teach. *11,* 172 (1973).

Briefly describes a "highly-structured, content-oriented, two-semester, introductory" technical physics course for 35-40 students that proceeds in one-week units. Fifteen-minute weekly recordings, available on cassette recorders in the library reserve room, are used to guide the student through the textbook and workbook. Two recorders suffice for the class. Eighty per cent of the students used the recorders one or more times each week.

43. Thorsland, Martin, *et al. An Instructional Exploration in College Physics. The Use of Audio-Tutorial Methods in Introductory Physics at Cornell University* (1971) ED 059 038.

Good discussion of the problems and procedures for implementing A-T. No evaluation of effectiveness.

44. Mayer-Pani. Un esperimento didattico del tipo multi-media. Il Giornale di Fisica 13, 276, 1972.

(A teaching experiment of the multi-media type). Some optics subjects have been taught in the final class of a secondary school and in a third or second university year for physicists or mathematicians, using a number of new methods (audiovisual aids, programmed instruction, tests, etc.). The content of the course has been based on Feynman vol. II. The results are discussed.

45. Fiske, A. James; and Kersey, Timothy. "Physics is Great!" Phys. Teach. *12,* 25 (1974).

Describes a popular high school physics course that makes use of (among other things) audio recordings for textbook chapter summaries, student book reports, modularized teaching, group examinations, physics-related projects in other high school departments, and a study unit in which the student writes a study unit.

46. Butzow, John W. and Pare, Roland. "Physical Science: A Multi-Media Facilitated Course" J. Coll. Sci. Teach. *2.* 29 (October 1972).

Describes a college physical science course for elementary education students that uses portions of the Physics for Non-Science Students (PSNS) and College Introductory Physical Science (IPS) curricula. Multi-media presentations of laboratory tasks are used along with individualized progress and a contract grading system. Evaluaton of achievement and attitude.

47. Black, Howard T. and Poorman, L. Gene. "Multimedia Systems Approach in College Physics Laboratories'. Sch. Sci. Math. *70,* 277 (1970).

Examples of experiments, demonstrations, and exercises used in three university physics laboratory courses. Some Harvard Project Physics materials are used. Increased enrollments and student interest reported.

48. Branson, Robert, K. *Formative Evaluation Procedures Used in Designing a Multi-Media Physics Course.* (1971) ED 050 140.

Studies student preference and performance with several instructional formula in order to find best combination.

49. Ferko, P. "New Forms of Pedagogical Practice in Physics". Fyzika ve skole, 1970, vol. 8, no. 5.

The article assesses the efficiency of pedagogical practice to date and stresses the need for the elimination of certain negative implications. Industrial television and its uses are cited as an example of a means towards this end.

50. Egner, K. Application of Closed Circuit TV during physics lessons. Aud. Viz. 10, 672–675, 1973.

The author gave the same lesson in three ways: first personally, second with the assistance of TV in his presence, and lastly with TV in his absence. The results of checking of learning effectiveness showed no essential difference among the three forms.

51. Brody, H.; Parkinson, P.D.S.; and Selove, W. "Use of Video Tapes in Advanced Laboratory". Am. J. Phys. *42,* 605 (1974).

Taped video lectures each 30–55 minutes in length have been used to instruct all students in a junior-senior modern physics laboratory about the use of the equipment. Student checks out cassette of the lecture from the library. Tapes are not polished productions and professor still visits laboratories to check progress and answer questions.

52. Carlson, Elof Axel. "Teaching by Television: A Critique" J. Coll. Sci. Teach. *2,* 15 (February 1973).

A refreshingly candid report on a failure in television teaching of a large course in biology for non-science majors. The author used two different techniques (lecture and "documentary"), both of which disappointed the students. Comparison with network documentaries make the present failure understandable. Anyone considering using instructional television for large groups should read this article.

53. Eddy, John Paul. "Ten Years of Educational TV Teaching". Sch. Sci. Math. *71,* 623 (1971).

An informal account of ten years of elementary and secondary science TV teaching in New Mexico, USA, by George Fischbeck. Discusses advantages of TV teaching, ways to involve classroom teachers, programme scheduling difficulties, emphasis changes during the ten years, and plans for the future.

54. Sund, Robert B.; and Tillery, Bill W. "The Use of the Portable Television Tape Recorder in Science Education". Sci. Ed. *53,* 417 (1969).

Suggested uses of video tape record for teacher improvement, training prospective science teachers, educational research, and direct teaching uses. Suggestions only, no report of trials.

55. Welliver, Paul W. "Using Educational Television as an Effective Tool in Science Education". Sci. Ed. *53,* 95 (1969).

Reports on the use of educational television in North Carolina, USA, including a ninth-grade physical science course broadcast as daily lessons (since 1959) and methods course for science teachers (since 1966). Discusses improved identification of state programmes and the effective "in-service training" for teachers that result from broadcast science courses.

56. Robson, M.J. Question time: a radio science series for African primary schools evaluated. Educ. Broadcasting Int. *6* 1973.

The writer describes the study of comprehension of a year-long series of radio science lessons by a sample of 460 African Upper Primary school children in Rhodesia. He concludes that about half the children in the sample understood and learnt from much of the material, that a further quarter comprehended and assimilated only relatively trivial aspects of the broadcasts while the remaining quarter gained little or nothing from the listening experience.

57. Harris, B.R. "Broadcasting and the teaching of science in secondary schools". S.S.R. *53,* 182 (1971).

Outlines the role of, and the restraints on, the use of television in secondary school science teaching.

7 New approaches to teaching and learning in schools

The period 1960–75 has been characterized by a growing awareness that the results of educational research do have application in the schools and by rapid developments in the fields of curriculum revision and methods of teaching. A greatly extended range of teaching techniques has become available. These place more emphasis on learning by children and less on direct teaching by the teacher and rely more on discovery than on revelation. This chapter based on a paper written by E.J. Wenham discusses these trends and looks ahead to the next few years.

7.1 DEVELOPMENTS

Today few curriculum developers in the field of school physics are unaware of the work of the Geneva school of Piaget with its analyses of the stages of intellectual development and of the growth of basic mathematical and scientific concepts in children [1]; of the application of taxonomies of objectives [2]; of the development of curriculum models [3]; of the analysis of the conditions under which learning takes place [4]; of the examination of the interactions between pupil and teacher [5]; of the central position of the role of language [6]; of the place of evaluation and assessment as a source of feed-back to both teacher and taught [7] and of the facilities offered by educational technology [8].

Other influences demand our attention. Students today are encouraged to be more self-confident, and the teacher finds he has to earn the respect of these highly critical students. There is a trend towards acceptance of the view that education is a branch of social engineering, an appreciation of the political nature of the decision-making process in education, a growing realisation that education is concerned with change and, in some countries, a significant shortfall in the production of teachers of mathematics and physics often associated with a marked decline in interest in science and technology generally.

The developments in the form and structure of physics teaching which have marked the period include the appearance of such first generation curriculum development projects as P.S.S.C. [9] and Nuffield 'O' level Physics [10] with their emphasis on the cognitive and, to a lesser degree, on the affective domains; the growth of a desire to make physics more significant and relevant to the pupils' perceived needs (e.g. Harvard Physics [11]; Nuffield Secondary Science [12]); the effect of the re-thinking of the nature of science and scientific enquiry associated with Popper [13] and Kuhn [14] and the application of such views to school courses; the consequences of the introduction of the so-called 'new mathematics' and, latterly, the development of integrated science programmes [15] in a wide variety of forms.

7.2 RESPONSES

The teachers of science in the schools have responded to these and other pressures in a remarkably resilient way. In discussing such responses it must be noted that, to quote the report [16] *Science Education in Nineteen Countries*: "in the English-speaking nations there is a marked empirical approach to science teaching with an emphasis on laboratory work and practical experiences. The continental European nations would appear to have built up a strong theoretical tradition, with less emphasis on investigation and enquiry. Japan has developed independently a pattern strikingly its own. The developing countries, however, face common problems. They are confronted with a rapidly expanding school system, a critical shortage of trained teachers as well as a lack of materials and facilities for the teaching of science."

Central to the development of modern teaching strategies has been the realisation that school science time is provided in order that children may learn rather than that teachers may teach. Even so it is probable that Flanders' observation [17] that there is a better than 60 per cent chance that the teacher is talking in a classroom at any given moment remains true.

The wide range of teaching techniques now available makes it necessary for the science teacher to consider carefully the objectives of his teaching and then to choose the technique which he judges will be most effective in the light of all the circumstances. The increased emphasis which has been placed by some of the English-speaking projects on pupil laboratory work is an example. Such work is 'learner-centred' but may also be teacher managed or even 'stage-managed' discovery. The concern is that of providing the student with personal experience of science; he becomes a 'scientist for the day'. It is characteristic of this approach that practical and theoretical work are brought together and interact one with the other. Planning, organizing and conducting lessons using this style is necessarily more complex than in the traditional laboratory class where the experiment is designed either to confirm the theoretical exposition of the teacher or to measure some attribute of the material under test.

Continental European countries have, as has already been noted, a strong tradition of teacher demonstration. In the pure example, the student is passive, but this need not be so. Demonstrations which require student participation [18] are now much more common; indeed a notable feature of the recent past has been the encouragement of more effective demonstration techniques by projects which also have been concerned to develop class experimentation. An outstanding example is the use of student to student demonstration in Nuffield Advanced Physics [19].

The traditional divisions of physics (heat, light, sound, etc.) have largely been replaced by groupings built around a central concept (e.g. waves) or by work based on an agreed topic. In this latter case, the work centres around a situation, topic or theme which is usually related to the interests expressed by the pupils. This approach encourages excursions outside the normally accepted bounds of the subject into, perhaps, its social implications or its history. Although more usually associated with younger pupils [20] the technique has been extended to older ones [21]. Children working in this mode may be grouped into small teams, each working on some special aspect of the topic. In some cases, students undertake individual project work: for example, the Nuffield Advanced Physics Project [19] requires a student to undertake an experimental investigation into a problem either of his own invention or chosen from an extensive list.

Some teachers use a 'circus of experiments' to provide the opportunity for individual learning and to free themselves for face to face discussion with individuals. "The circus uses a series of experiments . . . usually related to a common theme so that pupils may move from experiment to experiment in any order, the order being dictated sometimes by the availability of experiments to be done, sometimes by the teacher directing pupils to appropriate ones. Sufficient experiments are set out to engage an entire class and at the same time to ensure that there are enough to keep all pupils working hard all the time. Some pupils will complete fewer pieces of work than quicker ones, but will gain sufficient experience in any area chosen for study." [22].

The group work which is so often contrasted with whole class teaching has, more recently, been extended in the direction of individual learning. The best known example is probably the Intermediate Science Curriculum Study [23] initiated at Florida State University. Such a development is a necessary reaction to pressures in some countries for the teaching of children in classes which are undifferentiated in ability (mixed ability grouping). Teachers have tended to achieve the necessary individualization of approach either by providing work sheets which are common to all students in the class but which achieve differentiation by allowing different periods of time for completion to different children or by writing the simplest material first and setting a series of break-off points for individuals. In the long run, one might expect the work units to become truly individual were it not for the overwhelming work load on the teacher.

Independent learning materials must engender the proper conditions for learning. Gagné [4] suggests that the stages which characterise a learning unit whether of the traditional or the individualised type may be listed as:

1. Gaining and controlling attention.
2. Informing the student of expected outcomes.
3. Stimulating the recall of relevant background.
4. Presenting the stimulus situation.
5. Offering guidance for learning.
6. Receiving and providing feedback from learning.
7. Appraising performance.
8. Providing for the transfer of knowledge.
9. Ensuring retention.

Incorporating these into a work-sheet presents a formidable challenge.

Both the traditional class and the individualized modes of teaching may employ the mastery-learning [24] style in which a student who performs poorly in a summative test is directed to an activity designed to deal with the difficulties revealed – often in a small group session or by individual tutoring.

The relationship with the self-paced study programmes which are usually associated with the name of Fred Keller [25] is evident. That model has three steps (presentation, response, consequence) and incorporates both formative and summative evaluation. The plan has been used more extensively at the school/university interface than elsewhere. In this context the work of Postlewaite [26] at Purdue University deserves mention even though the use of the audio-tutorial at the school level appears to have been limited presumably because it demands considerable expenditure on hardware.

Developments in educational technology are considered in another chapter. Nevertheless one important development has been observed in the textbook itself. The traditional physics textbook employs the impersonal mature language of the adult rather than the creative language of the children, [27] its readers; it lacks appeal to the student and leaves little room for the imagination. All too often, it attempts to be encyclopaedic. This is changing; and among recent texts which adopt a different style those of Jardine [28] may be singled out.

It is a short step from a book to a programme. In the sixties this appeared to be highly promising with a great deal to offer. Today it appears doubtful if the resources required to prepare such programmes can be spared from more essential tasks.

An allied technique providing for rapid feedback of student response and understanding is the 'feedback classroom' [29]. Such a room is equipped with a device which enables the individual student to signal his response to a multiple-choice question displayed as the lesson proceeds. This signal is displayed at the teacher's bench so that the teacher has a complete indication at any instant as to the progress of each individual student.

An important question raised by these and other teaching developments concerns the size of classes. In Asia one hears of sixty to seventy as the norm: in the West thirty appears to be accepted. Even where individual learning is introduced, the school authorities may insist that a teacher remains responsible for the 'normal class'. A critic might question the assumption that any particular number is appropriate, since under some conditions, a group of 100 may be acceptable, whereas under others the ideal size is one.

A technique of interest in this context is that of team teaching [30] in which small group discussions (tutorials) and larger group lectures are combined. The advantages claimed are the variety of teaching and of viewpoints provided, the opportunity for the teachers concerned to specialize and to watch one another teach (normally a rare, but invaluable experience), and the provision of chances to work in the tutorial mode. The indications are that the method is more generally applied in interdisciplinary programmes than in the teaching of a single science.

Where science department heads exist there has been a change of role. It is now recognised that successful changes to a new curriculum, a new method or a new organization demand a serious attempt to change the attitudes, beliefs and methods of teaching of the teachers involved. Increasingly, therefore, the teacher responsible for the science department in a school sees his role as managerial, and concerned with planning, co-ordination, persuasion and evaluation. Where, for example, a school moves from a streamed (selected groups) to a non-streamed (mixed ability groups) structure, a strong commitment by the head of the department to the non-streaming is as essential as is his ability to devise means for effective cooperation among his colleagues in exploring the implications of the decision.

The trend away from the 'streamed' class which is characteristic of the school systems of many European and developing countries to the 'unstreamed' or 'mixed ability class' is currently presenting severe problems in some countries. Evidence suggests that the concept of the 'mixed ability' group is itself imprecise and that the change has been accompanied by little evaluation of the teaching. However, the process does seem to be more than a fashionable whim. Social reasons for teaching in heterogeneous groups are powerful and there is little hard evidence to support the view that brighter children are inevitably held back by being taught in such groups. There is concern, however, that such children may become frustrated, bored or complacent.

7.3 PROBLEMS

Such a plurality of responses to a rapidly developing situation may find the teachers of physics ill-prepared, may offer a threat to their status and may conflict with the culture within which the school operates. To teach in a way which may expose the teacher's own lack of knowledge or understanding demands great self-confidence and the ability to step away from the security of the known to the insecurity of 'let us find out together'. The recognition that 'science sits between the question and the answer' demands a new attitude towards both scientific knowledge and children learning science.

The teaching of physics is now required to be outward rather than inward looking. This presents a dual challenge, concerned on one level with the integration of the school sciences and on another with the social implications of science. Can the sciences be integrated successfully throughout the secondary school course, or only in the earlier years? What are the implications for tertiary education? Teachers are expected to apply new methods to unexpected situations and, at the same time, to present a view of science towards which they may well be unsympathetic. Students are faced with the prospect of making value judgments about science and its applications and their teachers with the need to leave such judgments open in their teaching. Teachers may themselves have a model of physics which implies that physics is good, is self-contained and exclusively concerned with natural phenomena. This is not society's model, however, and the students are trapped between the two views. Resolution demands an attitude change on the part of the teacher and this is very difficult to bring about. Yet, if the conflict is not resolved, physics may well suffer the fate of Latin as a school subject. Of course, parts will then be absorbed within other disciplines, but previous experience of that has not been entirely happy.

The teacher will also find technical problems. Whereas the Geneva school concentrates on the importance of action in early learning, implying that concrete experience and manipulation are of major importance, the Russian psychologists have pointed to the importance of language as an accompaniment to action, while Bruner and his colleagues stress the importance of developing the ability to manipulate ideas symbolically and particularly through speech. Evidently action and talk go hand in hand in ensuring effective learning. So teachers must themselves encourage both; they must encourage the pupil to talk and they must themselves learn to listen to what the pupil says and to understand its meaning. This is not easy for there is a strong tradition of formal, impersonal, adult talking and writing in school science. Teachers of physics have to understand that children learn by doing, by thinking, talking and writing about what they have done; and this requires time.

As concept formation in children is a progressive process related to intellectual maturation, social interaction and individual activities, the physics teacher and the psychologist, working together, might expect to detect the readiness of an individual student for a particular concept. The teacher himself should ensure that the application of the curriculum closely follows the stages of intellectual development in the child. This is of obvious significance to the physics teacher whose concern is so often with abstractions. Responses to this question are beginning to emerge [31] and more must be expected.

A trend towards the use of materials designed to promote individualized learning raises the question of the capability of the teacher to produce suitable packets of material (work-sheets, etc.) since the time required is so very large. Centrally produced materials will be welcome, but to be useful, such materials must be flexible, of high technical quality and short. Then the teacher will be able to construct a course which is suitable for his own class and his own style of teaching by selecting from the wide range of packets on offer. Such a course could respond rapidly to such changes as experience will show to be necessary. It may be that teachers' centres (where these exist) could provide for a cooperative effort in the production of such materials.

Individualized learning packets may provide an answer to those problems which follow from the introduction of mixed ability groups in countries moving away from a selective system. They may also provide the means to give every child the right to enjoy and learn the same physics.

The teachers themselves have it in their hands to implement change and to respond to the challenges presented to the schools. But they may themselves constitute a conservative counter-trend for they were themselves successful within the system. Necessary changes may well be inhibited by those most able to respond.

In countries where the requirements of public examinations are widespread and perhaps rather inflexible, it is more difficult to achieve changes in curriculum content and teaching technique. Science subjects are vulnerable because they are readily examinable. With respect to curriculum content, there appears to be a wide belief that there is in science a certain body of 'knowledge' which is unchanging. Furthermore this unchanging 'core' should be examined in its entirety and therefore should be taught in its entirety.

Even where opportunities to experiment in the field of examinations exist (as in the Certificate of Secondary Education examination in the UK) teachers are unwilling to take risks: facts are easy to examine, initiative in experiment is difficult.

But examinations are not alone in exerting pressures on the teacher; employers, parents and even tertiary education often combine in the effort to inhibit change.

7.4 SOLUTION OR RESOLUTION?

Teacher education (discussed in another chapter) can contribute a great deal to the building of that essential self-confidence which the existing situation demands of its teachers. Improvements in both pre-service and in-service education of teachers are needed urgently and it is fortunate that major contributions have been offered, for example, in the UK by the Science Teacher Education Project [32] and in Venezuela by 'Estudios Libres'. Such projects can make a very significant contribution to raising the low status of the teacher, to the dissemination of curriculum change and to the development of innovations among the teachers.

Many, perhaps a majority, of physics teachers will be unaffected by such courses and must depend on other agencies to keep them in touch and to combat their isolation. Where they exist and where they are oriented to the development of teaching as a profession in the same sense that medicine and law are professions, science teacher associations and science education centres are important agents in the task; they can encourage small scale but widespread curriculum development, can disseminate information about techniques and attempts to solve specific problem situations and can ensure that there is adequate discussion of the new whilst preserving the valuable features of the old. Such organizations may well prove to be the most effective agents for the dissemination of the important and relevant findings of educational research among the teachers and we would recommend school systems to encourage their development.

We recommend that authorities with responsibility for school systems should give very careful thought to the impact of change, whether imposed or evolutionary, on individual teachers and on individual children. Such change too often threatens the status, expertise and self-confidence of the teacher and leads inevitably to a disastrous lowering of his spirits ('morale'). There must be respect for the initiative of the teacher; his views should always be canvassed before change takes place. Humane administrative procedures are always the most effective in developing cooperation.

We recommend that, so far as is possible, physics in schools should be taught in the mother-tongue of the children; and that prospective curriculum changes should be supported by carefully-planned programmes of guidance for the teachers concerned and that this should also be given in the mother-tongue.

We suggest that the universities should accept a major role in assisting necessary change since their expertise and guidance are rightly respected by government agencies. We consider that each university needs to encourage active collaboration with schools in respect of physics teaching.

We consider that the physics community itself has a duty to the schools, that it should play a positive role in the fields of educational development and research and that it should assist the schools in the implementation of beneficial change. The wisest advice that it can offer is to urge the teachers to worry less about the content of their physics courses and to worry more about the need to educate the children to be conscious of some problems and to be aware of some solutions in the field of physics.

We recommend that institutions concerned with the education and training of teachers should provide their students with a wide repertoire of skills and knowledge based on the need to do what they can with what the country can afford. Then they may be prepared for change and equipped to operate in a wide range of situations.

There is a fundamental uncertainty in education today. Expressed in our terms, the question which demands an answer is 'Why teach physics?' rather than 'How should physics be taught?'. In some countries the answer is quite clear – to prepare for entry to a university. But this is the concern of a tiny minority of the children in the schools. An answer in such terms is no longer acceptable. We have to recognise that physics is an integral part of human culture and that it should be presented in this context. Many of the most important decisions which have to be made in our society are in fields in which physicists work. It is therefore important that every citizen has some appreciation of science, its methods and its limitations. If the attitudes of citizens towards physics are to be helpful physics must be taught as a human activity which is seen to have relevance to the individual in his social environment.

7.5 BIBLIOGRAPHY

1. Inhelder, B. and Piaget, J. *The Growth of Logical Thinking from Childhood to Adolescence.* London, Routledge and Kegan Paul, 1958.
2. Bloom, B.S. *The Taxonomy of Educational Objectives.* London, Longman, 1956.
   Gronlund, N.E. *Stating Behavioural Objectives for Classroom Instruction.* N.Y., Macmillan, 1970.
3. Bruner, J.S. *The Process of Education.* Harvard, University Press, 1960.
   Bruner, J.S. *Toward a Theory of Instruction.* Harvard, Belknap, 1966.
   Tyler, R.W. *Basic Principles of Curriculum and Instruction.* Chicago, University Press, 1949.
   Taba, H. *Curriculum Development, Theory and Practice.* New York, Harcourt, Brace and World. 1962.
4. Gagne, R.M. *The Conditions of Learning.* 2nd Ed., New York, Holt, Rinehart and Winston, 1970.
5. Flanders, N.A. *Analysing Teacher Behaviour.* Reading, Mass., Addison-Wesley, 1970.
6. Barnes, D. and Britton, J. *Language, the Learner and the School.* Harmondsworth, Penguin, 1969.
7. Gronlund, N.E. *Measurement and Evaluation in Teaching.* N.Y., Macmillan, 2nd ed., 1971.
8. Richmond, W.K. (ed). *The Concept of Educational Technology.* London, Weidenfeld and Nicolson, 1970.
   Taylor, L.C. *Resources for Learning.* Harmondsworth, Penguin, 1971.
9. P.S.S.C. *Physics,* Boston, Heath, (3rd ed.) 1972.
10. Nuffield Science Teaching Project. *Physics Teachers' Guides 1 to 5.* London, Longman/Penguin, 1967–8.
11. Project Physics. *The Project Physics Course.* New York, Holt, Rinehart and Winston, 1970.
12. Nuffield Science Teaching Project. *Secondary Science 1–8.* London, Longman, 1971.
13. Popper, K.R. *Conjectures and Refutations.* London, Routledge and Kegan Paul, 1969.
14. Kuhn, T.S. *The Structure of Scientific Revolutions.* Chicago, University Press, 1962.
15. Richmond, P.E. (ed). *New Trends in Integrated Science Teaching 1–3.* Paris, Unesco, 1971–4.
16. Comber, L.C. and Keeves, J.P. *Science Education in Nineteen Countries.* Stockholm, Almqvist and Wiksell, 1973.

17. Flanders, N.A. *Teacher influence, pupil activities and achievement.* Washington, U.S. Dept. of Health, Welfare and Education, 1965.

18. Mendoza, E. Experimental Seminars. *Trends in Physics Teaching II.* Paris, Unesco, 1970.

19. Nuffield Science Teaching Project. *Advanced Physics Teachers' Handbook.* London, Longman, 1971.

20. Science 5–13. *With Objectives in Mind.* London, Macdonald, 1972.

21. Schools Council Integrated Science Project. *Patterns 1–4.* London, Longman, 1974.

22. Sturges, L.M. Problems in teaching Science to non-streamed classes. *School Science Review.* London, vol. 55, no. 191. December 1973, p. 224–232.

23. Intermediate Science Curriculum Study. Morristown, N.J. Silver Burdett, 1970–3.

24. Block, J.H. (ed). *Mastery Learning; theory and practice.* New York, Holt, Rinehart and Winston, 1971.

25. Green, B.A. Physics Teaching by the Keller Plan at M.I.T. *New Trends in Physics Teaching 2.* Paris, Unesco, 1970.

26. Postlethwait, S.N. et al. *An integrated experience approach to learning.* New York, Burgess, 1964.

27. Rosen, H. The language of textbooks, in Britton, J. (ed). *Talking and Writing.* London, Methuen, 1967.

28. Jardine, J. *Physics is Fun 1–4.* London, Heinemann, 1964.

29. Hollings, K. in *Journal of Programmed Learning.* London, vol. 1, no. 17.

30. Warwick, D. *Team Teaching.* London, University of London Press, 1971.

31. Shayer, M. and Wharrey, D. Piaget in the classroom. *School Science Review.* London, vol. 55, no. 192, March 1974, p. 447–458.

32. Sutton, C.R. and Haysom, J.T. (eds). *Innovation in Science Education.* London, McGraw-Hill, 1974.

OTHER BOOKS RELEVANT TO THIS TOPIC

33. Sutton, C.R. and Haysom, J.T. (eds). *The Art of the Science Teacher.* London, McGraw-Hill, 1974, for Science Teacher Education Project, 162p.

    The thirteen papers included provide a succinct guide and an extensive bibliography relevant to the educational background to physics teaching, to the methods which are available and to the development of courses.

    Other books in this series include *Readings in Science Education* and *Innovation in Teacher Education.*

34. Comber, L.C. and Keeves, J.P. *Science Education in Nineteen Countries: an empirical study.* Stockholm, Almqvist and Wiksell, 1973.

    The report on school science by the International Science Committee of the International Association for the Evaluation of Educational Achievement (IEA).

35. Hurd, P. DeHart. *New Directions in Teaching Secondary School Science.* Chicago, Rand, McNally, 1969.

    An examination of recent trends in secondary school science curriculum development in the U.S.A. and of the perspective they provide for new directions.

36. Goodlad, J.S.R. *Science for non-scientists.* Oxford (U.K.), the University Press, 1973.

    An examination of objectives and constraints in the presentation of science to non-specialists which includes a thorough examination of science in school with special reference to UK experience.

37. Lewis, J.L. *Teaching School Physics.* Harmondsworth, Penguin (for Unesco), 1972.

    A source book offering material on both the theory and practice of teaching physics at the secondary level in which special attention is paid to the developing countries.

38. Unesco. *The development of science and mathematics concepts in young children in African countries.* Nairobi, 1974.

39. Unesco. *Asian conference on the development of science and mathematics concepts in children.* Bangkok, 1972.

40. Unesco. *Pilot project on the teaching of physics.* Unesco, Paris, 1967.

41. Recsam/Unesco/DSE. *New approaches to the teaching of Physics in Asia.* Penang (Malaysia), Recsam, 1975.

8

The effect on physics education of a better understanding of the psychological process of learning

The human sciences have made considerable progress in the last fifty years and are now in a position to make a worthwhile contribution to the teaching of science. Recent curriculum development work in science education throughout the world has made educators ask searching questions about the way science is being taught. This chapter, based on an original paper by Lucie Leboutet, is concerned with the convergence of these two lines of thought. The development and trends in the psychology of learning are followed by a critical analysis of current work. Finally a number of recommendations are made for future action.

8.1 DEVELOPMENT AND PRESENT DAY TRENDS

The psychology of learning is one of the areas which has been most thoroughly explored by the psychologists since the beginning of this century. It may be examined from several angles: general, developmental, differential. The last two aspects concern more specifically children, adolescents and the young adults who attend our primary and secondary schools and our universities. A more general study would take in a fourth aspect: educational. We shall limit ourselves here to pointing out the pedagogical application of the facts of learning when these appear of immediate relevance.

8.1.1 General Psychological Study of Learning

(i) Definition of learning

Although the task is not easy, we shall attempt a definition of the word 'learning'. In the strict sense of the word, learning is regarded as a sufficiently permanent change in an organism, manifesting itself in a modified behaviour pattern. It occurs when a like situation is repeated and strengthened by practice. Learning is a transformation of the subject that cannot be confused with other modifications such as fatigue, sensory adaptation, maturation. This transformation itself is not directly observable; what is observable is performance. In the broadest sense learning specifies the final condition of a subject who has acquired, by practice, a certain piece of knowledge or the mastery of a certain skill, during a period of time.

(ii) Different types of learning. Consequences for the school situation and the learning of physics

The phenomena of learning take on very varied forms whose classification differs according to the theoretical positions adopted by their authors. But these psychological theories do not seem to us to be of immediate interest to the educator. Hence we shall turn to the work of psychopedagogy. The examination of forms of learning which can be produced in class leads in general to a definition of the hierarchies of learning. Though straightforward in the cases of White [54] and Jensen [18, 47] (associative level and cognitive level) they are elaborated further in the cases of Ausubel [2] and Gagne [64]. We shall use here the classification of Gagne, while adapting it to physics and substituting for hierarchies of types of learning, a hierarchy of content.

The conditioned response is considered the simplest form of signal learning. It is met with at all levels of the zoological scale. It was studied by Pavlov (1849–1936; Nobel Prize 1904).

It presupposes that a neutral stimulus (the sound of a bell, for example) can trigger off a reaction (like the salivation of a dog) if this stimulus has been sent out at the same time as a stimulus which normally triggers off the reaction (the intake of food in the animal's mouth). In this way the generating of fear in children could be explained.

Instrumental conditioning is another form of response to a signal, but a more precise one, implying a muscular response to a stimulus as shown below:

S ------------------------------------ R

stimulus   response

The response can be gradually perfected, as in the training of animals, when the animal is rewarded by being given food or drink. By virtue of the 'Law of effect' (Thorndike, 1932) the correct response is 'reinforced', and the other responses vanish from the behaviour pattern of the animal. The proximity in time of the response in relation to the stimulus, and the repetition of the stimulus play an important part.

A particular example of this form of learning is the 'operant conditioning' of Skinner. We are going to devote a few lines to this because of the pedagogical application developed by the author. Skinner has presented his studies within the general framework of an analysis of the behaviour of organisms (1938) and has extended them to the verbal behaviour of man (1957).

A simple experiment of the operant conditioning may be described as follows. A rat placed in a cage in front of a lever learns to lower the lever in order to get food. Initially the manoeuvre is fortuitous, but if the rat thereby obtains food, it is consolidated and repeated by the animal in the same circumstances, and so is learnt. It is then said that the response has been reinforced.

Reinforcement, defined empirically, is therefore the appearance, after the subject's response, of an event which increases the probability of the reappearance of that particular response. If, on the other hand, a response is not rewarded, it ceases to exist. By providing or withholding these reinforcements, it is possible gradually to mould the animal's behaviour.

It is possible in this way to inculcate discriminating learning habits and motor learning habits in animals, in children and in man. Man, moreover, is capable of verbal learning. In Skinner's view, this does not differ in nature from other types of learning and the techniques to be applied to it are no different. Skinner's idea was to apply to teaching the benefits of knowledge gathered about learning phenomena through the medium of laboratory experiments which dealt with animals (rats, cats, pigeons). It is therefore postulated that these learning processes do not differ from one another. In Skinner's view, what is learnt at school are mainly verbal responses, identical in nature to other responses. Teaching consists, then, of organizing the conditions of reinforcement under which the pupils will learn.

Physics, which is a structured science, lends itself well to programmed learning for its content can be translated into objectively identifiable activities. Skinner himself has constructed such a programme. Of 1900 inventoried programmed courses in 1970, 36 per cent concerned mathematics and logic, and 40 per cent concerned scientific subjects.

A dozen studies carried out in different countries seem to support the view that programmed teaching of physics often proves more efficacious than traditional methods. It has at least the merit of specifying for educationalists the type of responses they expect from pupils in the course of learning. In traditional teaching the objectives are often only vaguely formulated – for example, to develop reasoning powers, the experimental approach, or to form the mind. These objectives are not translatable into explicit behaviour patterns on the part of the pupil, so that one cannot judge if they have been achieved. Programmed teaching in physics cannot and must not be achieved solely on the verbal level. A programmed course can be used to guide the student in the observation or analysis of a situation, for example practical work in physics. The Unesco pilot project relative to physics teaching provides a remarkable example, since laboratory experiments are carried out by the pupils themselves within the framework of the programme.

Let us extend the analysis of the different forms of learning and apply them to the case of physics. In addition to the verbal learning patterns, the following may be enumerated:

(a) *Sensory discrimination in learning*. The individual becomes capable of distinguishing forms, dimensions, colours, movements, sounds, acoustic intervals and rhythms and the multiple combinations of these factors which characterise objects or phenomena. All these discriminatory facets play a large part in daily life, in technology and in science.

(b) *Motor and perceptive-motor learning*. These forms are the underlying elements in technical skills. They result from the coordination of movements of hand and eye. They appear as chains of motor responses often themselves organized into patterns of complex responses.

Since the Second World War technical skills have been studied in the armed services and industry. There are few data relative to the school situation. Yet laboratory work, involving measuring, titration, and decanting of liquids, has been studied, as have the manipulating and adjustment of machines: ammeters, microscopes, oscilloscopes [32, p233–242].

(c) *Concept learning*. For example, force, work, current, light rays, mass, weight, speed, wave, particle . . . . Several definitions of each concept could be given, according to the theoretical framework in which one is placed.

From the behaviouristic point of view, to learn a concept is to learn to respond to stimuli in terms of the abstract properties of objects. These properties may be colour, length, number, position . . . Experimental studies have used relatively simple objects. The studies have not progressed far because of the inherent difficulties which include problems of language, and the perception of social interactions and of higher mental processes.

From the cognitive point of view, a concept is an intellectual abstract representation of an object. To this definition may be added the historical dimension. The concept learned links up the past experience of a subject with his present day experience in relation to the outside world.

Here are a few experimental results drawn from the United States, Soviet, Romanian and Polish work, relevant to the state of concept learning.

It is standard practice to bring to bear several intellectual operations in the formation and learning of concepts. In the first place, there are operations of abstraction following which certain properties of an object or a situation are isolated. These properties are distinguished according to their differences and similarities. The concept can only be made clear by the discovery of useful similarities. The United States investigators designate them by the term 'positive instances' and the Soviet as 'essential properties'. For the former a positive instance comprises one or several attributes of the concept, a negative process (or counter example) does not contain them. The experimental results which might concern physics are as follows:

When the concept to be learned must be extracted from visual stimuli, it is all the better grasped when the useful characteristics are easily seen. Discrimination is made easier.

One must simplify the task of discrimination. In physics a sketch of apparatus should not include non-essential parts. Yet the use of such a sketch could raise problems when the student is confronted with the real apparatus which contains these other parts [32, p128–130].

The characteristic attributes of a concept are learnt more easily when the latter is presented to the pupils in a great number of different contexts. The multi contextual presentation facilitates the abstraction of features that are common (Hull, 1920).

It is difficult for pupils to acquire a concept from the presentation of negative examples only. One must first obtain a clearly defined positive representation of the concept. But the presentation of negative instances prevents the pupils from coming to false conclusions to which they might be led either by lack of discrimination or by over generalization. Experimentally the best educational strategy consists in presenting simultaneously the positive examples and counter examples [66]. Such a strategy is used in the Unesco pilot project (1967, p17).

(d) *The learning of principles, rules, laws and theories*. In its simplest form a principle or a law can be considered as a chain of two or of several concepts, for example: 'bodies expand when heated'. It follows from this definition that the learning of the chain calls upon previous learning of the concepts. Moreover, the chain must be learnt both on the verbal and on the conceptual level. The teacher must be vigilant about achieving both these conditions.

But concepts, principles and laws are not learnt in isolation. The knowledge of an individual is organized in structures where the numerous interconceptual relationships interact: temporal, spatial, causal. This established fact is all the more important in that maths or science are themselves logically structured. They are presented as such to the learner and so, according to the premises of developmental psychology, he will encounter great difficulty if he himself does not have the logical structures necessary to their understanding.

The concepts of physics are woven into a network of relationships constituted by laws and principles which, arranged in hierarchical order, form in their turn systems, structures and theories such as quantum mechanics, geometric optics or the theory of electrical circuits. The introduction of new maths into physics aims at imparting more vigour to these structures (and perhaps increases their difficulties for the student).

Analytical studies by Gagne [10, p149–156] and his collaborators have arranged in hierarchical form the sequence of knowledge to be mastered in order to succeed in assimilating a given area of mathematics or physics.

The systemization of knowledge through the establishment of causal relations has been well described by Soviet authors [32, p130, 133].

At school level, Ausubel [2, p148] advocates an educational strategy which favours cognitive structuration by the employment of two processes,

(i) the use of introductory verbal material to establish a bridge between what the learner knows already and what he needs to know as a starting point, and

(ii) implanting into the pupils prior knowledge elements which will act as 'anchors' for some of the new knowledge ('subsumers').

A few general experimentally established results can bring this paragraph to a conclusion.

(i) Retention is better when principles and not just facts have been learned [2, p44].

(ii) There is positive transfer if the learning of one task facilitates the learning of another (negative transfer in the contrary case). For the transfer operation to come into play the principle must be used in the greatest number of contexts possible.

(e) *The learning of problem solving techniques – learning by solving problems.* There is a problem for an individual when he finds himself confronted by a situation which is new to him. The response to the situation-problem is not immediately available in his repertoire of responses.

In our particular pedagogical perspective a problem can be conceived as an end or as a means. The first case is the more traditional: the problem allows the teacher to test the knowledge acquired by the pupil – which is a process of evaluation. For the pupil the problem compels him to make his knowledge operational. When he has found the solution he will have learnt something, for he will know how to supply the response to problems of the same kind. It has been experimentally demonstrated that one learns how to solve problems. This ability has been called 'learning set' by Harlow. In the second option, the problem is considered as a means most suitable to favour learning. Gagne [64] defines 'hierarchies of learning' according to which learning by means of solving problems requires the bringing into play of previous rules necessary for the construction of new rules which override them and bring about a solution.

(f) *The motivation of the pupil.* Many theories of learning and research findings do not appear immediately usable in school. It is indeed difficult to apply to the child or to the adolescent results which have been established in the domain of animal psychology. The question is nevertheless too important to be passed over in silence. Traditionally, motivation is conceived as the dynamic factor in learning, one which provides direction to the activity and gives it its vigour. Several motivating factors have been invoked, implementation of which is left to the initiative of the teacher in the absence of satisfactory scientifically based guidelines. Curiosity is often mentioned; it seems firmly established in animal species, and in children whose questions and manipulatory activity manifest their desire to acquire new knowledge. If the aims of the particular course of study are fully explained to the pupils then they are likely to be more interested. Rewards and punishments are well known to educators as well as social reinforcements: rank, order of merit, prizes, etc.

8.1.2 Developmental Aspects of Learning

8.1.2.1 *The work of Piaget*

The theory and results of very important research work by the Swiss psychologist Jean Piaget will provide us with the elements of this chapter devoted to the developmental aspects of learning. It is around his work that we will be arranging the results of his followers or critics.

The theory of Piaget concerning the developmental evolution of intelligence does not rest on theories of learning based on the stimulus-response model. Between the stimulus and response, there exists, for Piaget, the organism and its structures [53]. But as Apostel has indicated [39], it would be possible to integrate the Piaget theory with the S – R model by means of the *scheme*. In Piaget's work, a scheme of action is established either by a series of reactions or by a sequence of reactions and events; it may be, for example, a simple reflex action of a complex behaviour pattern in problem solving. The scheme is transformed by assimilation and accommodation: this transformation is called *learning*. Confronted by new situations, schemes of action which are already functional can be either assimilated or modified by adjusting to the new situation.

It is not here a question of the complication of a more or less lengthy chain in the form S – R. Besides the stimulus is not experienced passively by the subject who transforms it.

Between the two processes, namely accommodation (which modifies the scheme) and assimilation (which alters the object) a balancing process occurs. The latter becomes stabilized when the resultant adaptation satisfies the need. In this theory, the need is part of the process of modification of the scheme of conduct; it is the conative aspect. The motivation resides within the process, and therefore has not been studied in isolation.

The transformation of schemes is sufficiently concretely defined when it is a matter of the construction and co-ordination of sensory-motor schemes in the very young child. It ends in the construction of the object notion and schemes of time and space (Piaget, 1961). Beyond this stage (at about eighteen months to two years old) when organized speech appears, the action interiorizes; it is no longer possible to follow concretely the evolution of schemes and hence their learning. It is for this reason that Piaget's work does not bring useful data to bear on the understanding of the processes of learning as such. But its contribution to the understanding of the intellectual development of the child and the adolescent is fundamental for the psychologist and for the psychopedagogue. It is particularly so for the teacher of mathematics or of physics, to whom it supplies the psychological basis of his teaching.

Let us remind ourselves of the essentials in the work of Piaget and his school. Their results stem from a great number of ingenious experiments which have a bearing on almost all areas of knowledge, in particular a knowledge of the physical world. The fundamental ideas are as follows.

(i) *The central idea is that of operation*. It derives from that of 'action' particularly dear to the author. 'Operation' in the Piaget sense of the term is a mental action. It modifies one's appreciation of a particular object and helps the individual to understand the nature of the transformation that has taken place. Here are some examples: show a piece of apparatus to a class, classify objects or put them in ranking order. The author calls such simple operations 'logical'.

(ii) *Properties of the operation*. The operation is reversible, it can function in opposite directions, for example – addition/subtraction; join/separate. In this way it makes the building of structures possible.

An operation never takes place in isolation, it is always linked to another. Examples: a number never exists alone, it is linked to a sequence of numbers; a class is not isolated, but linked to other classes of the division which do not possess the characteristics of the class under consideration, for example the positive/negative examples of classes of concept; a spatial relationship assumes a space.

The result is that the operation is always part of an overall structure. The correct role of operations is to form systems which are 'groupings' in the case of qualitative systems (simple classifications, double entry tables, serialized relationships), or 'groups' when it is a matter of spatial, temporal, algebraic, geometric, topological structures, etc. These structures are not directly observed facts. But their existence may be inferred from the explicit operations of which a subject is capable.

The comprehensive systems are developed according to a certain number of chronological stages, developing in a constant order. The ages of appearance vary according to the subjects, what the experience is, the instructions, or the cultures. The principles of balance and of reversibility are also applicable to these systems.

The stages of the construction of operations are as follows:

– sensory-motor stage, about the first 18 months of life

- symbolic, preconceptual thinking, beginnings of speech, 18 months to 4 years (on average)
- intuitive thought – from 4 to about 7–8 years old
- stage of concrete operations, 7–8 to 11–12 years old
- stage of formal operations – from about 11 years of age

The concrete operations are concerned with objects that can be manipulated, for example, classification, serialization, time and space relationships, ideas on number, elementary logic of classes and relationships. From this stage of relationships, learning in mathematics and elementary physics becomes possible. According to Piaget, the child is only capable of reaching beyond the simple observation of facts if he has at his disposal suitable schemes or operations that allow him to establish relationships between them. It seems that this stage is covered in two distinct phases – Phase A, 7–8 years: formation of concrete operations (classes, relationships, number and space) and of the first retentions (conservations); transitivity. Phase B, 9–10 years: achievement in concrete operations, conservation of weight, natural coordination of space.

The constitution of formal operations begins on average at about 11–12 years old. From this moment the adolescent begins to be able to reason about propositions, on hypotheses and no longer merely about objects. He achieves new structures in two phases – Phase A: operations involving propositions, combinations, possible coordination of two systems of reference; Phase B: groupings of the four transformations that are involved in operations: negation (or inversion) N, reciprocity (or symmetry) R, correlation or inversion of the reciprocal C, which with the identical relationship I constitutes the group 'INRC'.

The generalization and balancing of the reactions of the preceding stage constitute the final stage. Piaget has established the narrow dependence between the acquisition of these new structures by the adolescent and the possibility of applying the methods of discerning and of proof to physics subject matter [16].

Before envisaging an eventual application of these results to the teaching of physics it is right to ask if the results have been confirmed by other specialists in developmental psychology.

8.1.2.2 *Critical comments on the work of Piaget*

In so far as the work has been translated into English it has given rise to an important proliferation of experiments centred above all on the characteristics of the different stages. The work of the Swiss school lays open to criticism a certain number of methodological criticisms [2, p192–193]; they have therefore been taken up again more systematically and in experimental conditions which are far more rigorous.

The authors have found certain variations in detail in the ages of appearance of the different stages. There is increasing evidence that the average child reaches the stage of formal operation rather later than at the age 11–12 often quoted. It may well be nearer 14–15 and it is now clear that many children never reach this stage. But the results obtained in different places confirm on the whole the order of succession retained by Piaget [21], [57], [60], [72].

In general the facts he has established are scarcely called into question, but his interpretations are still disputed. For example, according to Piaget, a subject who interprets reality can only do so if he has at his disposal pre-existent schemes or 'operations' of logic which enable him to assimilate the datum. May it not be asked whether learning which is in direct contact with reality would allow the necessary frameworks to be established? A certain number of researches are aimed in this direction [44], [55], [62], [82]. Their results are only partially concordant. The only subjects which profit from training are those which at the starting point found themselves at a level approximating to that of the acquisition of useful structures of logic.

8.1.2.3 *Current and possible application to physics*

Having as the end in view that teaching should be more closely adapted to the pupils, several steps can be taken and several directions for research may be followed up.

(i) *The general initiation of teachers to psychopedagogy*. This training is far from being currently administered in all school systems. Even though, in some countries, training of physics teachers includes courses on child or adolescent psychology, these courses are of little use to the physics teacher: little effort has been made to adapt courses to the specific needs of the physics teacher. Of special interest is the manner in which the psychologist can cooperate in the development of curricula and the training of future physics teachers, and the responsibility that both, psychologist and physicist, have to share in this process.

(ii) *Establishment of school programmes to match up with the stages of mental development*. An example is furnished by 'Science 5 to 13' prepared in the United Kingdom. The programme is centred on the pupil who is learning, in particular on the operations which he is capable of performing successfully: classifications, serializations, concrete operations, the start of formal operations. In order to take into account differences between the subjects with regard to the age of accession to the different levels, the programme unfolds with great flexibility within the area of chosen interest. The different scientific disciplines are not treated disparately but are handled as if they were integrated.

In a general manner, the scale of development must allow for the construction of grids of educational objectives which must evolve with the progress of the pupils.

Didactic experiences are imagined, sometimes in conjunction with mathematics. They aim at teaching to young pupils coherence, objectivity on an intellectual plane and reciprocity of views on the social plane. It is thus that R. Karplus (University of California) has perfected apparatus in order to lead the subjects to compare their points of view, to establish cause by interaction and not by simple temporal series, to discover relationships of proportion, fundamental to elementary physics.

(iii) *Study of the adequacy of programmes in operation for the mental development of pupils*. The critical examination of the content of a programme in terms of the criteria of mental development may lead to the assertion that this programme is too difficult for the subjects. Such is the conclusion of Shayer, quoted by Lovell [74] whose work deals with the content of the Nuffield GCE O-level courses in physics and in chemistry. Verification was carried out by means of an examination test consisting of two types of question: concrete or abstract. Only five per cent of the 192 subjects had mastered the course.

(iv) *Study of the operational capacity of pupils*. The standardization of Piaget tests in various countries (Canada, France, Switzerland) tends towards the elaboration of tests at an operational level. More interesting than the classical tests of intelligence, they can be used to judge whether the pupils are suitable to receive scientific instruction and at what level. They therefore allow the teaching to be more satisfactorily adapted to the pupils. It is in terms of this information that the teachers can set up experiments and create situations suitable to getting children to move from one level to another, and so hasten their cognitive development.

8.1.3 Differential Aspect of Learning

8.1.3.1 *The existence of individual differences*

The study of individual differences in the processes of learning and in the acquisitions which issue from them is much less advanced than the general and developmental studies. This deficiency in psychology is all the more regrettable in that the differences between individuals or between groups constitute the stumbling block in teaching. If such differences did not exist, educational problems would be greatly simplified. The existence of differences between the learning capacities of pupils is an established fact, but in order that the relative differences may be accurately identified they must appear in the same pupils at the same time. The behaviour of pupils must be identified in the course of experiments or tasks which bring out that variable. When this is the case, the results of different tasks, differentiated according to the pupils, can lend themselves to studies of correlation which are the basis of factorial analyses. Some forty studies have been concerned with individual differences in learning [47]. Several are described in J.P. Guilford [13]. They show that there exists no general factor of learning. The usual conception, according to which intelligence is the general aptitude for learning, does not stand up to an examination of the facts. Intelligence and aptitudes in learning comprise a great number of different components. Whether they have in common one or several of these factors depends on the task or the particular test designed to test intelligence.

8.1.3.2 *Classification of individual differences*

Positing the absence of a taxonomy of individual differences in learning, Jensen [47] proposes several methods of presentation:

1. The first concerns the distinction between the extrinsic differences (chronological age, mental age, intellectual quotient, personality characteristics, cognitive style) and the intrinsic differences inherent in the phenomenon of learning itself, which constitute the intersubject variability in the learning process. This variability appears in the course of tasks described according to a scheme inspired by the tridimensional model of Guilford on the dimensions of the intellect [13, p63]. Jensen defines as follows the three dimensions of the classes of variable in learning tasks: 1) types of learning, 2) procedures (distribution of the exercise, length of task, similarity between tasks), 3) content or modality (verbal, numerical, spatial).

2. The second concerns the distinction between tests and the processes adjacent to the patterns of intercorrelations between tasks. The first are designated by 'phenotypes', the others are 'genotypes'.

In the framework of his model, the author presents results on sequential learning, the range of memory, etc. They do not appear to us directly to concern the learning of physics. But the model proposed by the author and the methodological considerations which accompany it could be taken up again for the purpose of a precise analysis of different tasks required in the learning of this discipline. Let us note, moreover, an important result stated by the author: 'in a laboratory situation a subject behaves differently between a first experience and those that follow and that happens whatever the task. One initial performance is integrated with difficulty into the factorial. structure. The subject needs a certain time to become adapted to the laboratory situation. This affirmation eliminates the value of a number of classical experiments in learning which base their results on a more or less short period during which the subject is in a laboratory situation, and without exposing him to repetitions of the experiment.'

In conclusion, we may note the sparse results in the field of individual differences. They are as yet unable to furnish for educationalists the bases which will allow them to adjust their strategies of teaching to the characteristics of learning in their pupils.

8.2 CRITICAL ANALYSIS OF WORK IN PROGRESS

8.2.1 General Psychology

From all the considerable mass of work, we have extracted some data which it is possible to use in teaching: research on the formation of concepts supplies results which are transferable to physics and programmed teaching constitutes the direct application of a theory of learning to didactics.

Nevertheless one may well feel astonished at the disproportion existing between the immense quantity of experimental work and the relative thinness of its application at least in the Western world. In some East European countries, where researches have been initiated through laboratory studies on animals, current work on learning is conducted in schools, precisely where the processes take place on a large scale.

Let us consider a few elements in the argument.

Animal psychology versus human psychology

Research on laboratory animals has supplied a considerable quantity of data in rigorous and purified conditions which have permitted the building up of theories. The latter are obliged to fulfil, in psychology, the same heuristic role as theories in physics. But human beings, as distinct from animals, are capable of acquiring an almost limitless repertory of symbolic and verbal knowledge. Knowledge tends to be organized and its structuring is even a condition of its retention and its ultimate recall [41]. Can one then explain human behaviour as specialized, complex and hierarchical in terms of animal reactions which are so qualitatively different?

Laboratory psychology versus psychology in the field

The situations. (a) The laboratory situations have in general little significance for the subject who is doing the learning, and motivation is therefore fairly artificial. It is in this way that the subject is called on to learn meaningless syllables that he will never meet in the real situation, or lists of paired words instead of meaningful verbal material. (b) The experimental material is simplified and arbitrary; for example the experiments on the formation of concepts comprise, most frequently, a simplified material. The concepts which emerge are very far from concepts related to physics.

The subjects. Let us recall Jensen's results [47] relative to the time needed for acclimatization by the subjects in a laboratory situation, a factor which is often not taken into account.

Isolated learning versus continuous learning

The situations. (a) In a laboratory situation the stimuli do not change in the course of the test. In a school situation they vary constantly. (b) A concept is learnt in isolation in the course of an experience. Now a concept exists through the relationships which it maintains with other concepts, for example: positive instances opposed to counter examples. Now pedagogical reality deals with conceptual areas where all the parts are interdependent. Psychological research has not been troubled by the problem of organizing knowledge and more particularly by that of the structuring of concepts.

The subjects. We have defined learning as the transformation of a subject who moves from a state A to a state B. State B is evaluated by means of performance. In customary experimental conditions, state A is often taken as equivalent to a zero state: no account is taken of the background history of subjects, nor of individual differences between them. An analogy with physics will make us understand the importance of the question. If one wishes to anticipate the future state of a system in physics, following a transformation, one must not only know the law governing the transformation, but also the initial state of the system, or the conditions at the extremities. As regards the teaching of physics, the initial state includes in particular the entirety of the previous representations of the pupils. They constitute a system of knowledge starting from which new learning will be able to take place. According to Ausubel [2, p127] the existing cognitive structure is the principal factor which determines significant learning and its retention in the area under consideration. But retention and the phenomena of recall (or memory) are not studied simultaneously with learning in experimental research.

Programmed teaching

Among the reproaches addressed to programmed teaching let us highlight a few criticisms relating to the processes of learning themselves:

(i) It has been possible to reproach Skinner because his programmes do not produce a transfer effect in the pupil who is learning. Education, however, aims at promoting transferable responses from school to everyday life, either in the present or the future.

(ii) Criticism is directed at these programmes for not allowing the use of a method in which the progression by short discontinuous stages would make all synthesis difficult for the pupil.

(iii) The champions of programmed learning proclaim that the pupil is active, but in what sense is he active? If he only has to supply a narrowly predetermined response, the activity is not at a very advanced level. That is why some research, still insufficiently widely disseminated is applied to the study activity of the subject while he is learning [71]. Moreover, they use experimental apparatus contiguous to programmed learning which allows one to manipulate with precision the experimental variables.

8.2.2 Developmental Psychology

(i) According to Piaget's theory, operations which characterize a certain stage are organized in complete structures. The result is that when a child has reached a certain stage he possesses the corresponding structures. He must therefore be capable of mastering every task which implies bringing those structures into play. Experience proves that there exist variations between tasks which are formally identical. Piaget himself establishes their existence as regards such concepts as substance, weight and volume [61], [74].

(ii) The researches of Piaget are not centred on pedagogy. If a great number of his results are usable in physics it is because the author has largely drawn on the apparatus and concepts of this discipline himself. From these themes he establishes the birth of logic, the themes constituting a means and not an end. The result is that the concepts are chosen in isolation. On the one hand, the author does not propose to make an exhaustive analysis of them; on the other he does not study the relations between them nor their organization. The object of his work is the acquisition of structures of logic, not the building up of a conceptual framework of physics by the pupil. In particular, the author does not take account of the behaviour of the pupil confronted by physics.

(iii) The study of operations in the Piaget sense does not neglect everything which is not 'operation' and which, in the learning of physics, can play a considerable part; in particular experimental inferences, understanding of visual symbols, schematization . . . .

(iv) Finally the work of Piaget describes essentially the development of the West European child. According to Bruner [7] the cognitive growth of the child depends on its activity, it is subordinate in large measure to the cultural and linguistic milieu in which it takes place.

8.3 PROPOSALS FOR ACTION AND RESEARCH

8.3.1 Choice of the Learning Situation

The most efficacious path of research concerning the processes of learning appears to us to be research in the school situation or milieu. It is at school that one can analyse the conditions, the variety, the nature of these processes as much as the characteristics of the learners, confronted by school conditions. It is by following continuously the pupil evolving in his milieu that one can better grasp his transformations. Yet each school situation, each school, each class, possesses characteristics likely to make their imprint on the pupils. Without comprehensive comparative studies, strengthened with a precise description of the characteristics, one runs the risk of imputing to this or that artifact or to local conditions too important a role in learning.

It is not because the school situation is complex that we must abandon all hope of discovering generalized laws of learning. On the one hand, laboratory research has shown the way towards a definition of precise conditions for the manipulation of variables: for example techniques inspired by programmed teaching may well make a contribution. On the other hand, it is possible to manipulate the school situation in an almost if not actual experimental situation if one shows some imagination. The modern techniques of experimentation and of analysis of data allow complex situations to be tackled frontally. They merely require the close collaboration of teachers, psychologists, psychopedagogues, administrators and even computer scientists and linguists.

The value of these researches is that they are immediately available to the educator who can transform his teaching in consequence, by modifying his objectives, or his methods, or his techniques of evaluation.

8.3.2 Description of Physics to be Learnt

Having defined our framework for research, we now propose defining the components of the material to be studied. In many modern physics programmes, the sequence and articulation of the concepts and manipulative skills have been carefully defined in the objectives. What appears to be lacking in our perspective is a description in psychological terms of the tasks to be learnt. One would hope at first for a precise and exhaustive analysis of the types of learning required in physics: mathematical language, facts, schemas, rules, relationships, laws, concepts, methods, skills, techniques, structuration of knowledge and attitudes towards problem-solving. The motivation of students of both sexes in respect of different learning situations, e.g. problem solving, abstract thinking, etc. requires basic research. It is then that experiments could be carried out on these different varieties of learning, inspired by laboratory psychological researches making it possible to determine the optimum procedures of learning, applicable to the different modalities of contents (verbal, numerical).

8.3.3 Scientific Language and Communication

In this connexion a special paragraph may be devoted to one of the previous aspects (unfortunately one of the most neglected), namely scientific language and communication essential for the transmission of knowledge. We believe that additional research is needed in this field, including aspects of teacher-pupil and pupil-pupil interaction.

An enquiry carried out among hundreds of French students who had recently finished their secondary studies, has shown that among the numerous difficulties encountered by the pupils in the learning of physics, those of the scientific language loomed large. The vocabulary contains many technical words which have no significance for many of the pupils, and descriptions of units or words of everyday language which are used in science with a special precise meaning [22]. The linguistic difficulties extend beyond vocabulary difficulties. Gardner [65] presents lists of logico-grammatical terms, established by Strevens (1972); these terms correspond to notions which are sometimes grasped with difficulty by students, for example: causality (because, therefore, hence), restriction (only, unless, if, and only if, etc.). The problem tackled by Lewis [24, p60–61] would appear to merit studies of different languages carried out by physics, linguistic and psycho-linguistic experts. The linguist might be asked to establish catalogues of these semantic difficulties [79] and the psycho-linguist to study their impact on pupils according to the latter's level of development, level of learning or individual differences.

8.3.4 The Pupils

(i) *The psychological study in relation to the learning situation*

The area of operations has largely been covered by Piaget and his successors, but less attention has been paid to formal operations. It would be more useful to the physics teacher to know what the pupil is capable of doing in the subject in terms of the stage in which he finds himself, than to know the detail of the operations of logic at this level (Shayer, quoted by Lovell 1974). Investigations are needed in this direction, centred on the tasks of learning indicated in 8.3.2.

This area does not cover all the intellectual activities required for the learning of physics, in particular those that Piaget designates as 'infralogical' and which concern time and space. Piaget does not deal with attitudes, for which we have very little information (for example, attitudes towards experimentation and science, motivation).

(ii) *How pupils interpret knowledge before being exposed to the teaching of physics*

Work bearing on several hundreds of French adolescents from 11 to 18 years of age has made it possible to bring out the following facts [22]:

(a) Before any teaching takes place, the children have a certain number of previous pieces of knowledge resulting from their contact with the physical and social milieu. This knowledge has a certain number of characteristics which differentiates it from notions of physics. The pupils' notions of quality and quantity tend to be oversimplified. For example, they could say that when a force is exerted on a body it makes it move at a high speed.

(b) Knowledge evolves with age, as predicted in Piaget's operational theory.

(c) In the course of initiation into physics, new knowledge does not necessarily modify previously held misconceptions. To justify a false intuitive belief, the pupils use precise but irrelevant scientific knowledge, or they seek a compromise between the two. For example: (i) spontaneous belief: the pupils believe that a gas or a vapour has no weight; (ii) school learning: all bodies have weight; (iii) result: if cigarette smoke has weight, it follows that it must contain solid bodies.

Ausubel [2, p336] characterizes these preconceptions as follows: "These preconceptions are amazingly tenacious and resistant to extinction because of the influence of such factors as primacy and frequency because they are typically anchored to highly stable related and antecedent preconceptions of a more inclusive nature; because they are inherently more stable (for example more general; less qualified, expressive of a positive rather than inverse relationship; predicated on single rather than multiple causality or on dichotomous rather than continuous variability); and lastly because resistance to the acceptance of new ideas contrary to prevailing beliefs seems to be characteristic of human learning. Some of the reasons for individual differences in the tenacity of preconceptions probably include those that are related to cognitive style, to such personality traits as closed-mindedness and to self-consistent individual differences in generalised aspects of reductionism in cognitive functioning."

It is essential to explore the area of these preconceptions, just as it is necessary to make an inventory of the entire range of erroneous conceptions subsequently elaborated by pupils in the course of learning.

Suitable experimental work is suggested by Berlyne [4, p255–261].

These conflicts already existed in Piaget's schemes and are explained by Inhelder and others [17].

A few directions for research relating to the processes of learning in physics have been sketched out here. We have not specified at this stage either the posing of the problem nor the means. Implementation would involve international collaboration, the establishing of multidisciplinary teams of research workers possessing means of dissemination and exchanges of findings.

8.4 REFERENCES AND BIBLIOGRAPHY

(*Recommended to physics teachers as introductory readings)

1. Austin, G.A. see Bruner, J.S. 1956.
2. Ausubel, D.P. *Educational Psychology.* New York, Holt, Rinehart, and Winston, 1968. 685p.
3. Bartlett, F. *Thinking.* London, Allen & Unwin, 1958. 203p.
4. Berlyne, D.E. *Structure and direction in thinking.* New York. J. Wiley & Sons, 1966. 378p.
5. Bovet, M. see Inhelder, B. 1974.
6. Bruner, J.S., Goodnow, J.J., Austin, G.A. *A study of thinking.* New York, Wiley, 1956. 330p.
7. Bruner, J.S., Oliver, R., Greenfield, P.M. *Studies in cognitive growth.* New York, Wiley, 1957.
8. Bruner, J.S. *The process of education.* Cambridge, Harvard Univ. press, 1963, XVI. 93p.
9. de Cecco, J.P. *The psychology of learning and instruction.* Englewood Cliffs, Prentice Hall, 1968. 1012p.

10.* Gagne, R.M. *The conditions of learning.* New York, Holt, Rinehart, and Winston, 1965, 308p.

11. Goodnow, J.J. see Bruner, J.S. 1956.
12. Greenfield, P.M. see Bruner, J.S. 1957.
13. Guilford, J.P. *The nature of human intelligence.* London, MacGraw Hill, 1971, 538p.
14. d'Hainaut, L. *L'enseignement de concepts scientifiques et techniques à l'aide de cours programmés.* Thèse, Université libre de Bruxelles, 1971, non publiée.
15. Hilgard, E.R. *Theories of learning and instruction.* Chicago, Chicago Univ. Press, 1964, 63rd Yearbook, Nat. Soc. Stud. Educ.
16. Inhelder, B., Piaget, J. *De la logique de l'enfant à la logique de l'adolescent.* Paris, Presses Univ. de France. 1955, 314p.
17. Inhelder, B., Sinclair, H., Bovet, M. *Apprentissage et structures de la connaissance.* Paris, Presses Univ. de France, 1974, 356p.
18. Jensen, A.R. *Genetics and Education.* London, Methuen & Co. 1972.
19. Jones, H.C. see McKenzie, 1970.

20. Koch, S. *Psychology: A study of a science.* New York, MacGraw Hill 1959.

21.* Laurendeau, M., Pinard, A. *La pensée causale.* Paris, Presses Univ. de France, 1962, XI, 228p.

Causal thinking in the child. International Universities Press 1963.

22. Leboutet, L. *De la notion au concept. Etude de psychologie génétique sur la physique élémentaire.* These d'Etat. Paris 1969, non publiee.

23. Leontiev, A., Luria, A., Smirnov, A. *Recherches psychologiques en U.R.S.S.,* Moscou, Editions du progress, 1966, 390p.

24. Lewis, J.L. *Teaching school physics.* UNESCO Source book, 1972, 415p.

25. Luria, A. see Leontiev, A. 1966.

26. MacKenzie, N., Eraut, M., Jones, H.C. *Teaching and learning.* UNESCO and the International Association of Universities, 1970. 209p.

27.* Piaget, J. *La psychologie de l'intelligence.* Paris, A. Colin, 1947, 212p.

The psychology of intelligence, London, Routledge & Kegan, 1950.

28. Piaget, J. see Inhelder, B. 1955.

29. Pinard, A. see Laurendeau, M. 1962.

30. Ripple, R.E., Rockcastle, V.N. *Piaget rediscovered.* Cornell Univ. 1964, 150p.

31. Rockcastle, V.N. see Ripple, R.E. 1964.

32. Simon, B. & J. *Educational psychology in the U.S.S.R.* London, Routledge & Kegan, 1963, 283p.

33. Sinclair, H. see Inhelder, B. 1974.

34. Skinner, B.F. *The technology of teaching.* New York, Appleton Cy Croft, 1968, 271p.

La révolution scientifique de l'enseignement. Bruxelles, Dessart, 1968, 314p.

35. Smirnov, A. see Leontiev, A. 1966.

36. UNESCO. The development of science and mathematics concepts in young children in African countries, Nairobi, 1974.

37. UNESCO. Asian expert seminar on the development of science and mathematics concepts in children, Bangkok, 1972.

38. Vigotski, L.S. *Thought and language.* New York, Wiley, 1962.

39. Apostel, L. *Logique et apprentissage.* In Apostel, L., Jonckeere, A., Matalon, B. *Logique, apprentissage et probabilité.* Paris, Presses Univ. de France, 1959, pp. 1–137.

40. Bogoaivlenski, D.N., Menchinskaia, N.A. *The relation between learning and mental development in school children,* in B. & J. Simon *Educational psychology in the U.S.S.R.* London, Routledge & Kegan, 1963, pp. 50–67, and *The psychology of learning,* pp. 101–161.

41. Ehrlich, S. *Les conditions de la mémoire verbale à long terme* in *Le comportement verbal.* G. Bramaud du Boucheron, R. Champagnol, P Coirier, S. & M.F. Ehrlich, Paris, Dunod, 1970, p. 217–273.

42. Fleshner, E.A. *Psychology of the mastery and application of some concepts in physics.* In Simon B. & J. *Educational psychology in the U.S.S.R.* London, Routledge & Kegan, 1963, p. 198–213.

43. Galperine, P. *Essai sur la formation par étapes des actions et des concepts.* In Leontiev, A., Luria, A., Smirnov, A. *Recherches psychologiques en U.R.S.S.* 1966, p. 114–176.

44. Greco, P. *L'apprentissage dans une situation à structure opératoire concrète.* In Gréco, P., Piaget, J. *Apprentissage et connaissance.* Paris, Presses Univ. de France, 1959, p. 68–182.

45. Greco, P. *Apprentissage et structures intellectuelles.* In Fraisse, P., Piaget, J. *Traité de psychologie expérimentale* VII. Paris, Presses Univ. de France, 1963, p. 157–207.

46. Inhelder, B. see Piaget, J. 1963.

47. Jensen, A.R. *Varieties of individual differences in learning.* In Gagne, R. *Learning and individual differences.* Columbus, Merrill books, 1967, p. 117–135.

48. Leboutet, L. *L'adolescent et la physique;* in Leboutet, L. *L'enseignement de la physique.* Paris, Presses Univ. de France, 1973, p. 74–102.

49. Menchinskaia, N.A. see Bogoaivlenski, D.N.

50. de Montpellier, G. *L'apprentissage.* In Fraisse, P., Piaget, J. *Traité de psychologie expérimentale.* IV, Paris, Presses Univ. de France, 1964, p. 115–177.

51. Mulerian, E.A. *Psychological characteristics of the transfer of technical skills in older schoolchildren.* In B. & J. Simon, *Educational psychology in the U.S.S.R.* London. Routledge & Kegan, 1963, p. 233–242.

52. Natadze, R.G. *The mastery of scientific concepts in school.* In B. & J. Simon, *Educational Psychology in the U.S.S.R.*, London, Routledge & Kegan, 1963, p. 192–197.

53. Piaget, J. et Inhelder, B. *Les opérations intellectuelles et leur développement.* In Fraisse, P., Piaget, J. *Traité de psychologie expérimentale.* VII, Paris. Presse Univ. de France, 1963, p. 109–155.

54. White, S.H. *Evidence for a hierarchical arrangement of learning processes.* In Lipsitt, L.P., Spiker, C.C. *Advances in child development and behaviour.* New York, Academic Press, 1965.

55. Beilin, H., Franklin, I.C. Logical operations in area and length measurement: age and training effects. *Child Devpmt.* 1962, *33,* 607–618.

56.* Bergval, P., Joel, N. *Le Projet-pilote de l'UNESCO relatif à l'enseignement de la physique.* UNESCO, Paris, 1967.

57. Braine, M.D. The ontogeny of certain logical operations. Piaget's formulation examined by non-verbal methods. *Psychol. Monog.* 1959, *73*, no. 5, 43p.

58. Cahill, H.E., Hovland, C.I. The role of memory in the acquisition of concepts. *J. Exp. Psychol.* 1960, *59,* 137–144.

59. Denhiere, G. see Le Ny, 1974.

60. Dodwell, P.C. Children's understanding of spatial concepts. *Canad. J. Psychol.* 1963, *17,* 141–161.

61. Elkind, D. The development of quantitative thinking, a systematic replication of Piaget's studies. *J. gen. Psychol.* 1961, *98,* 219–227.

62. Erwin, S.M. Training and logical operations by children. *Child Devpmt.* 1960, *31,* 555–563.

63. Franklin, I.C. see Beilin, H. 1962.

64. Gagne, R. Learning hierarchies. *Educ. Psychologist.* 1968, *6,* 1–9.

65. Gardner, P.L. Language difficulties of science students. *The Australian Science Teachers Journal.* 1974, *20,* 63–76.

66. Hovland, C.I., Weiss, W. The tranmission of information concerning concepts through positive and negative instances. *J. Exp. Psychol.* 1953, *45,* 175–182.

67. Hovland, C.I. 1960, see Cahill.

68. Hull, C.L. Quantitative aspects of the evolution of concepts. *Psychol. Monog.* 1928, *28.* Whole no. 123.

69. Joel, N. see Bergval, 1967.

70. Lawson, A.E. see Renner, 1973.

71. Le Ny, J.F., Denhiere, G. Le rôle du sentiment de savoir dans un apprentissage de connaissances. *Le travail humain.* 1974, *37,* p. 23–34.

72. Lovell, K., Ogilvie, E. A study of the conservation of the substance in the junior school child. *Brit. J. Educ. Psychol.*, 1960, *30,* 109–118.

73. Lovell, K., Ogilvie, E. A study of the conservation of weight. *B.J. Educ. Psychol.* 1961, *31,* 138–144.

74.* Lovell, K. Intellectual growth and understanding science. *J. of Res. in science teaching.* 1973, 1–19.

75. Morris, R.W. Interaction between linguistics and mathematical education. Symposium UNESCO Kenya, Nairobi, 1974. Linguistics problems encountered by contemporary curriculum development projects in mathematics.

76. Ogilvie, 1960, 1961, see Lovell.

77. Oleron, P. L'enseignement programmé I *L'Année Psychol.* 1964, 461–481, II, 1965, 99–116.

78. Oliver, R. see Bruner, 1957.

79. Phal, A. De la langue quotidienne à la langue des sciences et des techniques. *Le Francais dans le monde.* 1968, *61.*

80.* Renner, J.W., Lawson, A.E. Promoting intellectual development through science teaching. *Physics teacher.* May 1973.

81.* Renner, J.W., Lawson, A.E. Piagetian theory and instruction in physics. *Physics Teacher.* November 1973.

82. Smedslund, J. The acquisition of conservation of substance and weight in children. *Scand. J. Psychol.* 1961, *2,* 2–10.

83. Weiss, W. 1953, see Hovland.

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9 The process of course and curriculum development

This chapter, based on the original paper written by A.A. Strassenburg, begins with case studies of development and evaluation processes. Included with these there is a summary of responses from the project directors concerned to specific questions: these questions related to origins, staff, advisory groups, testing of material, communication channels, procedures used in dissemination, evaluation and availability of the product. The chapter also includes statistical data on other projects. The original author analysed certain features common to a number of curriculum development projects and made several recommendations which may be of interest to those organising future projects. The chapter incorporates modifications made by the working group concerned at the Edinburgh conference.

9.1 CASE STUDIES OF COURSE AND CURRICULUM DEVELOPMENT PROJECTS

This section contains a small number of case studies selected from approximately 100 course and curriculum development projects that have substantial physics content and have been described in the literature during the past five years.

9.1.1 Large Projects at the Secondary School Level

Large course development projects in physics have been undertaken primarily in the developed countries, particularly in the United Kingdom and the United States. Wide dissemination on an international scale has been successful only for a few courses at the secondary school level. Among these are the courses developed by the Physical Science Study Committee (PSSC), Harvard Project Physics (HPP), and the Nuffield Physics Project (NPP).

(a) *The Physical Science Study Committee (PSSC)*

The PSSC course was conceived by a group of university physicists in the area near the Massachusetts Institute of Technology in the late 1950's. They sought to produce materials that would treat most of the basic principles of physics using an approach similar to that used by scientists themselves. Processes such as experimentation, drawing inferences, model building, problem solving and logical deduction were emphasized. With the support of the National Science Foundation, a federal agency in the U.S.A., a textbook, teachers' guides, tests, apparatus for many experiments and approximately 50 films were produced over a period of ten years.

These materials were eventually adopted in their entirety by about one-third of the high schools in the United States, where decisions on the adoption of curricula rest with local Boards of Education, which often delegate the responsibility to the high school principal or to individual science teachers. A much larger number of teachers, perhaps as many as three-quarters of all U.S. high school physics teachers and substantial numbers in other countries as well, use selected PSSC experiments and films even though they do not follow the PSSC syllabus closely [1].

The PSSC text has been translated into several languages, including Spanish and Japanese. The adoption of the course by schools outside the U.S. has not always been successful. In a number of developing countries, efforts have been made to adapt the PSSC course to the needs of the local students. In other countries new projects have been organized that have developed materials more suitable for local use. All of these efforts, indeed even course development efforts at other levels and in other disciplines, were strongly influenced by the goals and techniques first proposed and used by the Physical Science Study Committee.

(b) *Harvard Project Physics (HPP)*

Project Physics was conceived and directed by Gerald Holton, James Rutherford and Fletcher Watson with Harvard University as a home base. Several features of this new course initiated or helped to accelerate trends in the design of new physics courses.

Project Physics was a pioneer in inserting a substantial amount of information on the historical development of the concepts of physics into a course that also treats the major topics of physics in a quantitative manner. In addition, the text includes many discussions of social and political factors that influence the behaviour of physicists. Ancillary readers include science fiction, poetry and humour.

The HPP directors recognised that different students learn in different ways and they wished to reach a wide spectrum of students on each of two scales: (1) from students with high aptitudes for mathematics and science to those with below average aptitudes; (2) from students interested primarily in science and technology to those whose interests lie primarily in literature and the arts. To accomplish this goal, they not only included a variety of subject matter, but they employed a variety of instructional materials. The course materials include not only student textbooks, laboratory apparatus and 16 mm films, but also supplementary readers that contain stories about physics and physicists, programmed workbooks that contain descriptions of experiments to perform and problems to solve and 8 mm single-concept film loops that display analysable data.

From its inception, Project Physics employed a testing system that involved large numbers of randomly chosen secondary school physics teachers who cooperated by providing feedback on their experiences in using early versions of the materials. The staff of Project Physics included professional evaluators, and the number and quality of published reports that assess the effectiveness of HPP materials in achieving project goals and in serving the needs of various kinds of schools and students set a new standard for course development projects [2, 3, 4, 5].

The directors of Project Physics have tried in two ways to avoid failures among schools adopting their materials. (1) Preliminary versions of the materials were released only to teachers and reviewers who were in close contact with the authors and evaluators. In this way all trials could be carefully controlled. (2) No permissions for direct translations of the original materials into other languages have been granted. Instead, each country wishing to adopt the HPP approach must undertake a project of its own that results in an adaptation of the HPP materials to local conditions. One such effort in Japan was conducted by a team of research workers led by Tae Ryce, Lecturer in Sophia University in Tokyo. Teachers who tried the course in Japanese secondary schools reported that students preferred HPP to the traditional physics courses taught previously. Despite this positive result, Tae Ryce feels that the time devoted to physics in Japanese high schools is not sufficient to allow adequate coverage of HPP topics. Thus continued use will require further adaptation.

(c) *The Nuffield Advanced Physics Project (NAPP)*

The Nuffield Advanced Physics course [6] was designed for 16–18 year olds of above average ability, roughly the same audience as that reached by PSSC. It served as a sequel to the earlier Nuffield Physics Project (NPP) designed for students in the 11–16 year old age bracket. The fact that this project, as well as other course development projects in the United Kingdom, was supported by a private foundation (Nuffield) rather than a government agency provides a contrast to patterns in most other countries.

Course development efforts were carried out largely by school teachers with some help from university professors. It gradually became clear that course development is slow and demanding work, and that if results are to satisfy the changing needs of many kinds of students, curriculum development must become a continuous process. As a result, some physicists turned to this activity as a full-time occupation. Seven different physicists worked a total of sixteen man-years developing the Advanced Nuffield course materials. Persons who are talented at this kind of creative work are soon identified by others in the business and are much in demand.

The NAPP course is now used in approximately 300 schools in England and Wales. This number has grown steadily since 1968 and now includes about 15 per cent of the potential student market. The reasons why adoptions of the major curriculum projects have never exceeded 30 per cent of the potential student market are complex and vary from country to country. These reasons include the costs of initiating a new course, lack of adequate teacher preparation, restrictions on the selection of course syllabuses and textbooks imposed by local and regional school boards, and widespread scepticism toward new programmes.

(d) *The Nuffield Advanced Level Physical Science Project*

This course is similar in level and in general approach to the Nuffield Advanced Physics course [6]. However, it contributes to a trend away from offering three separate science disciplines (biology, chemistry and physics) in the secondary schools. One manifestation of this trend is an increase in the number of high quality, interdisciplinary courses being taught in the secondary schools of several different countries. While these are offered more frequently to students who have not demonstrated unusual ability or interest in science than to those who have, there are notable exceptions and this Nuffield course is one of them. It covers mechanics, electric and magnetic fields, kinetic theory, chemical reactions, atomic structure and the periodic table, molecular bonding and electromagnetic radiation, all in a fairly rigorous and quantitative fashion. One benefit resulting from the integration of chemistry and physics is the elimination of duplication on such topics as atomic structure; another is that a unified treatment of all these topics can be more easily achieved.

(e) *The Man-made World*

This course was developed in the U.S.A., with support from the National Science Foundation, by the Engineering Concepts Curriculum Project group. As the name of the organizing committee suggests, it is more a course in engineering concepts than in physics. It is included here because it might well be elected by secondary school students in the U.S. instead of physics and therefore represents a trend toward the inclusion of material about the applications of physics at the expense of broad coverage of physical theories themselves. In the U.S. this might take the form of the addition of selected topics on technology, agriculture, health or the environment to conventional physics or it might mean the substitution of the Man-made World or a course in earth, space or marine science for a course in physics.

(f) *The University of the Philippines Science Education Centre High School Physics Course*

The Philippines are typical of countries that have discovered that courses produced in the developed countries do not serve their needs. The University administrators felt a need to upgrade the pre-college science experiences of their incoming students and they noted a lack of suitable materials on the market. They therefore undertook the task of materials production themselves with initial support from the Ford Foundation. The project that resulted is a model for cooperative activity on the part of several different groups with vested interests in the improvement of science education.

A total of nine university and high school physics teachers contributed to the production of the materials. An advisory committee consisting of textbook authors and curriculum experts established policy with regard to curriculum design and publication of the new products. A steering committee of scientists and technical experts reviewed the materials and recommended modifications in content and level. Ten high school teachers tested preliminary versions in the classroom; their comments led to two revisions of the initial efforts. The Science Education Centre, a University facility, distributed newsletters announcing goals and progress toward their implementation. Through a grant from the National Science Development Board, teachers were trained to use the new materials. The Philippine Association of Physics Teachers recommended adoption of these texts by the schools. Eventually the texts were approved by a National Board of Textbooks. Regional Science Teaching Centres were established which helped to disseminate the materials throughout the country. UNICEF funded teacher-training at the regional centres.

However, the book has been found difficult by many students, and even by some teachers in the rural areas. Teachers in schools with limited resources could not construct or assemble the necessary apparatus. Moreover, the text fails to match recent national goals and international trends. A second physics course was therefore launched.

While retaining the best features of the first effort, the current project is producing materials that relate physics to other disciplines and show the relevance of physics to the solution of social and environmental problems. To cope with an acute shortage of teachers trained in physics and to meet the needs and interests of the students, the materials are modular and will be taught in a self-paced or small-group format. Very simple equipment will be developed locally.

The new project is still a cooperative venture but is now characterized by a high degree of student involvement and more evaluation. Before any materials were produced, a nationwide survey was conducted to assess the abilities, needs and interests of the students and the adequacy of school facilities. As materials are prepared small groups of students provide feedback. The first set of materials are now being tested in ten schools. Clearly this is an example of a developing country using its own resources in an effort to satisfy national needs.

(g) *New Zealand Secondary Schools Curriculum*

In 1968 more than 80 per cent of all secondary schools in New Zealand were presenting their pupils for the PSSC form of the national examination. In spite of the numerous benefits of this course it was felt that PSSC was designed for a different kind of school system, parts were too hard and the text was too 'wordy'. Accordingly a new set of 'prescriptions' (a detailed syllabus) was undertaken in 1969. Initially the PSSC materials continued to be used while new teachers' guides, visual materials and textbooks were developed that conformed to the new prescriptions. At each stage comments were solicited (and incorporated) from teachers, university faculties and the Department of Education. The resulting curriculum is strongly influenced by PSSC and still uses much of its resource material, but represents local thinking and conditions. This experience may demonstrate a useful middle road between simple adoption of overseas packages and the development of national curricula from scratch. In effect it amounts to treating dissemination of the PSSC course in the way insisted upon by Project Physics (see above).

(h) *The Scottish National Working Party*

A relatively recent project, begun in 1973, makes use of many teachers in local working parties to produce materials with special attention to the needs of the bottom 20 per cent of student ability range. These materials are assembled, edited, and disseminated by a National Working Party, which also organizes evaluation through comments collected from teachers using trial materials, interviews with pupils, class observations, criterion-based tests as free as possible from the requirement for high verbal skills. It attempts to measure long-term growth in a small number of selected pupils. Materials prepared for the least able pupils have achieved remarkable success with pupils of the full ability range. It is accepted that the long-term part of the evaluation is extremely difficult.

(i) *A New Course for Indonesia*

The Ministry of Education in Indonesia is at present developing and testing a completely new school structure and system for possible dissemination in 1980. Physics is taught as a part of an integrated science programme for the first eight years of schooling and as a separate subject for the next four years. The instruction is in modular form. Each module consists of a basic unit, remedial units for those that need them and a large amount of enrichment material. The test taken at the end of each unit is primarily diagnostic and is taken only when the student judges that he or she is ready for it. The student texts are self-instructional and self-paced; the teacher acts as a resource, guide and counsellor, especially with respect to the choice of suitable enrichment or remedial work.

In parallel with this programme is another that will ensure that all government secondary schools have well-equipped laboratories. Fourteen hundred laboratories are now under construction and are being equipped.

Most schools will use an interim syllabus from 1976 until the new courses are ready. Meanwhile the new courses are being given an initial trial in eight widely scattered schools for years 1, 4, 6 and 9. The material will be rewritten and tried in more schools next year.

(j) *East African Secondary Science Project (SSP)*

Science courses based on the Cambridge Overseas Syllabus were used in East Africa before independence but these were not geared to the special needs of East Africans. After independence, the ministries of education in Kenya, Tanzania and Uganda collaborated with the Centre for Educational Development Overseas (CEDO) – CEDO is now merged with the British Council – to produce new courses. Subsequently Tanzania left the group. An international panel makes decisions concerning syllabuses and examinations, and divides development tasks between the countries. National panels implement recommendations and write draft materials.

The course provides for pupils in the first few years of secondary school. Trial editions of materials were provided free in duplicated form by the Kenya Institute of Education and sold in printed form by the Jomo Kenyatta Foundation, linked with the Ministry of Education. Materials include four years of pupils' books and teachers' manuals, slides (some with taped commentary) for pupils and accompanying notes for teachers. Published editions of the books are now widely used in Uganda for combined physics and chemistry courses, and in Kenya for physics as a separate subject.

Formative evaluation for the improvement of materials takes the form of weekly comments by teachers; these are compiled monthly and circulated to all trial schools. Based on these comments, individual teachers rewrite portions of the materials, which are tried out in the form of booklets and, after further trial, incorporated in the next trial edition of the complete books. After three drafts, definitive versions are usually written by a team of teachers and edited by one person.

In Kenya, a summative evaluation has been carried out in two phases. In phase one, two physicist curriculum developers visited the schools and solicited teachers' opinions. In phase two, pupils' test performances and opinions were studied. Pupils commented on all aspects of the curriculum. They were also asked to state one thing they liked least about the course and one thing they liked best. A large number of teachers were involved in writing the criterion-based tests. During a week-long evaluation workshop, attended also by college and university members of the national panel, participants analysed the results and delegated portions of the report to individuals.

(k) *A Course Development in India*

A major course development programme in India was undertaken by the National Council of Educational Research and Training assisted by Unesco and UNICEF. Syllabuses, textbooks, teachers' guides, and science kits for the primary and middle levels were made available to the State Governments to adopt or adapt and translate for their own school systems. An estimated 20 per cent of schools at these levels use the materials. An evaluation of material as used in the field has been undertaken with expert advice.

(l) *The Physics Teaching Project, Brazil (PEF)*

The Projeto de Ensino de Fisica (PEF, Physics Teaching Project) was developed at the University of Sao Paulo under the leadership of Ernst W. Hamburger. It began in 1969 without external support. After a preliminary version of the materials was tested with 6000 students the project obtained support from FENAME (the Ministry of Education and Culture's National Foundation for School Materials), which also takes responsibility for producing all written materials and laboratory equipment for the course. The development staff included university physicists, secondary school teachers, journalists and graphic artists.

Written materials for the student include a text, study guides, self-evaluation tests and optional reading material. Kits for experimental work are simple and inexpensive, including original items such as a sand stopwatch accurate to 0.1 second. Teachers' guides and teacher training courses were also developed. The subjects covered include Newtonian mechanics, electricity and electromagnetism.

The originators consider the present version of the materials to be preliminary and are seeking funds for evaluation leading to a thorough and careful revision.

(m) *Integrated Science Curriculum Development in the Commonwealth Caribbean*

Since 1968 six projects have been developed in the Commonwealth Caribbean; WISCIP (1968–71), MONA (1970–73), WISC (1970–73), SDSP (1972–), Slow Learners (1973–) and CARISO (1975–). CARISO is intended to be used in years 4 and 5 (pupils aged 14–15), while all the others are designed for use in years 1, 2 and 3 (pupils aged 11–14).

Of the three completed projects, WISCIP, financed by the government of Trinidad and Tobago, was prompted by the rapid growth in the number of secondary schools, which caused a demand for science teachers that exceeded the supply. This course was aimed at the needs of the pupils of average ability or better, while the two following projects, MONA and WISC were designed to serve a wider ability range. Teachers contributed to the writing of materials. WISC has been adopted in twelve other countries including three in Southern Africa. Comparative evaluations of MONA and WISC against other courses have been made by measuring pupil achievement in specified skills.

9.1.2 Projects at the Tertiary Level

(a) *The Berkeley and MIT Physics Courses*

Inevitably the ferment in secondary school science described above spread to more advanced levels. Several projects initiated during the early 1960's in the U.S.A. resulted in more rigorous and up-to-date introductory college courses for prospective physical scientists and engineers. The Berkeley Course is typical of this group.

The course materials include textbooks on mechanics, electricity and magnetism, waves and oscillations, statistical mechanics and quantum physics. In addition, the developers produced four volumes of laboratory experiments that exploit modern apparatus such as cathode ray tubes, oscilloscopes and microwave equipment. The course was designed for students who completed a course in physics while in high school and who are taking calculus concurrently.

The Berkeley Physics Course materials were produced in a manner different from that used by most other projects. Outstanding scientists were identified and assigned specific writing tasks. Their results were then used as components of the overall course output without the usual team rewriting and editing of each individual volume.

In a similar and continuing curriculum development effort at the Massachusetts Institute of Technology, preliminary text drafts by several collaborators have been considerably revised and made uniform in approach, principally by A. P. French. Films of demonstration experiments, computer-generated film loops and other learning aids accompany the texts. A "walk-in laboratory" [7] of demonstration apparatus gives students quick and direct contact with a range of phenomena, while a "project laboratory" [8] allows research-like concentration on a project selected by one student or a pair of students.

A trend that the design of these courses reflects is the movement towards two-year rather than one-year introductory physics courses in U.S. colleges and universities. Naturally the introduction of a two-year course requires that students begin their study of physics during their first year in a tertiary institution, whereas until 1960 it had been normal for many of them to postpone physics until the second college year.

(b) *Cooperative General Science Project*

This project, organized by four colleges in Atlanta, U.S.A. and housed at Clark College, was created in response to a felt need to teach science to non-science liberal arts majors in a different way to that used in teaching science and engineering majors. Though the course was designed for general use and was eventually exported to a number of colleges outside the Atlanta area, it did solve a particular problem in the four local predominantly black colleges and therefore received very strong support from them. The preliminary materials were repeatedly tested in the local colleges and were revised three times. Questionnaires were used to collect feedback information from students and teachers.

The publisher played a strong role in the promotion of the materials. Preliminary versions of the materials were distributed without cost to over 100 interested colleges. In addition, the U.S. Office of Education supported summer study programmes during which teachers were given an opportunity to become familiar with the philosophy and teaching techniques recommended by the project directors.

Many other courses developed during the past ten years have attempted to provide science literacy to non-science students. Not all are inter-disciplinary, though many are unconventional in their physics content. Not all were designed for exportation; many were created for special groups at particular colleges, but few of these survived beyond the day the innovator stopped teaching the course. However concern for reaching the student who is uncommitted to science has dominated college physics innovation since 1964.

(c) *Physical Science for Non-science Students (PSNS)*

Conception and planning for the PSNS course were novel in that they were initiated and guided by government supported professional organizations, the Commission on College Physics and the Advisory Council on College Chemistry. Major conferences were held even before the project staff members were identified; during these conferences the philosophy and content of the course were outlined.

As soon as preliminary course materials had been tested and revised, the course leaders held briefing sessions for publishers and apparatus manufacturers, invited proposals from them for the promotion, production and marketing of the materials and assigned the task of proposal review to the Project Advisory Board. This procedure worked well and has since been used by other project leaders [9].

The publisher invested heavily in promotional activities. One of the most effective tactics was the scheduling of one-day workshops led by project staff members to acquaint prospective PSNS teachers with the course materials and recommend instructional techniques.

This was perhaps the first government-supported college-level science course designed with a particular career goal in mind, in this case, elementary school teaching. The course was also unique (at that time) for two other reasons: (1) the laboratory materials were fully integrated with discussion in the text, (2) the course content was restricted to a narrow range of topics all related to a single theme (the structure of solids). All of these features have been built into other courses since that pioneering venture.

(d) *The Open University*

The Open University in the United Kingdom teaches mature students (over 21 years of age) who study in their homes. The courses offered are produced by teams of academics, educational technologists and television producers. The academics represent many disciplines and work full time producing course materials for the Open University. The courses consist of multi-media modules including books, radio and television programmes, audio-tapes, home experiment kits and group instruction during summer periods.

The use of Open University materials ranges from wholesale adoption of entire courses to limited use of specific components. As an example of the latter, lecture courses are now being built around sets of Open University TV programmes made available on film.

Over 50 000 students in the United Kingdom are now enrolled in the Open University. This style of instruction has been copied by Empire State College in the state of New York, U.S.A., as well as by other states and other nations. The expansion of more effective systems for delivering instruction to adults and other non-traditional students represents an important trend and presents a challenge to teachers of laboratory-based subjects such as physics.

(e) *Physics Syllabus for a Three-year Course offered in Indian Universities*

Some universities in India have adopted a new three-year programme. The students who enter this programme have completed twelve years of schooling, ten in elementary school and two in secondary school. The three years of work toward the B.Sc. degree includes twelve major examination papers, one on each set of topics in the outline below. One of these offers an option.

First Year:	Thermodynamics and the mechanical properties of liquids
	Electromagnetism and electronics
	Optics and quantum mechanics
Second Year:	Optics, statistical physics, thermodynamics and radiations
	Electromagnetism, solid state physics and electronics
	Quantum mechanics, atomic structure and nuclear physics
Third Year:	Quantum mechanics, spectroscopy and X rays
	Solid state physics and electronics
	Optics, electromagnetic theory and relativity
	Statistical physics, mean free path phenomena and thermodynamics
	Nuclear physics

Optional paper:

(a) development of physical thought
(b) teaching of physics
(c) design of instruments
(d) a project or a dissertation

Several features distinguish this new programme from more traditional Indian B.Sc. degree programmes. First, there is no separate exam for mathematics, because maths is integrated into all the physics topics. Secondly, the syllabus clearly exhibits a spiral approach. For example, quantum mechanics is treated in all three years, each time at a higher level of sophistication. Finally, the historical order in which the theories of physics evolved and the manner of their initial presentation has been abandoned whenever a different order or a more modern presentation results in greater simplicity or tighter logic. (More details about this programme can be obtained from Professor V.G. Kher of the Institute of Science at Nagpur.)

9.1.3 Smaller Projects Designed to Accomplish Specific, Limited Goals

(a) *The Pennsylvania Nuclear Science Project*

Several aspects of the objectives and procedures adopted by this project were somewhat unusual when first used. First, the goal of the project was to provide students at early secondary school levels with information about a complex technological problem not usually treated until the upper-class college level. Secondly, the project was initiated and supported by a state department of education. Thirdly, project staff performed duties associated with this project in addition to other regular responsibilities; no full-time staff were ever hired. Finally, the course leaders adopted the systems approach to curriculum design by establishing behavioural objectives for developers, by listing desired student competencies, skills and comprehensions, and by instituting pre- and post-tests to assess the success of the course materials.

This effort to solve a particular problem identified on a local level by organizing a project managed and supported by regional groups and by producing materials tested and used largely in state schools, may well be a model for future course development projects. The steady increase in the use of these materials and the favourable reports of independent evaluators suggest that this model may lead to success more often than efforts to use the output of large curriculum projects to satisfy the needs of local schools and their students.

(b) *Higher Education Learning Project (HELP)*

This project is representative of another new trend among physics educators: the introduction of improved teaching methods rather than the production of still more new materials. Project staff members, all university professors, try to identify teaching problems, design solutions and study new problems introduced by the solutions. They have focused on enhancing the responsibility of the learner for his or her own progress and a major effort has been to increase the amount of productive contact between learners and teachers.

Spread of the successful methods identified thus far has been accomplished primarily through informal contacts among colleagues. Evaluation techniques include interviews with students, classroom observation, questionnaires completed by students and faculty, analysis of test results produced by both experimental and control groups and study of videotapes made during classroom sessions.

With regard to the methods themselves, one that shows promise is the use of some class time for skill sessions [10]. These are organized problem solving sessions during which small groups of students attack prescribed problems designed so that specific skills must be known or acquired if success is to be achieved. Clearly the conception, dissemination and evaluation of methods like these will make demands on curriculum innovators very different from those they have become familiar with while attempting to produce new texts and laboratory materials.

(c) *Iniziativa Relativita*

In Italy a group of university professors and school teachers representing several cities assessed the possibility of teaching the concepts of special relativity in Italian secondary schools and ultimately produced materials for doing so. The general aims of the group were as follows: (1) to discover a didactic approach to special relativity suitable for Italian secondary schools, (2) to decide on the necessary related curricular changes, (3) to select existing teaching materials consistent with the results of (1) and (2), (4) to produce new materials such as notes for students and teachers' guides, (5) to test the materials in the schools and to obtain feedback from them, (6) to prepare evaluation instruments, (7) to conduct a controlled evaluation of the programme. To refine and implement these aims seminars were held. These involved 60 school teachers and 23 professional physicists from nine universities.

Since 1972 attempts by 25 teachers to use the materials have indicated that special relativity is indeed rewarding to teach because it arouses intense interest among both students and teachers. Some of the materials developed by project personnel were tested during these attempts. An evaluation involving the same teachers and offering courses in successive years to experimental classes and control classes were started in 1973–74 and is still under way. Twelve experimental classes and twelve control classes containing a total of about 600 pupils have participated. Preliminary results are encouraging. Additional information about this project can be obtained from G. Cortini, Istituto di Fisica dell'Universita, Rome.

9.2 GENERAL CHARACTERISTICS OF PROCEDURES USED BY COURSE AND CURRICULUM DEVELOPMENT PROJECTS

A survey [11] was conducted to gather facts about procedures used by those projects large enough to be listed in the International Clearinghouse Report [12]. The number of responses was only eleven, but even among these few certain trends could be discerned.

9.2.1 Project Origins

Most ongoing projects were initiated by college and university science faculties. The next most common prime movers were groups of science teachers in the schools. In isolated cases, projects were conceived and launched by university administrators, a professional teachers' association and a State Board of Education. Most respondents described as the primary motivating factor a sense of dissatisfaction with the science materials available at particular levels, in particular disciplines or for particular groups.

Initial project support came about equally from private foundations, federal agencies and State Departments of Education. One respondent reported that a private publisher paid the initial bills for materials production. Almost every project director acknowledged the influence of PSSC and the Nuffield Physics Project on the design of project goals and procedures. Several also mentioned Project Physics and the BSCS biology project.

9.2.2 Selection and Utilization of Staff

By far the most successful method for recruiting staff members was to approach persons who were known to be productive as a result of personal contacts or 'grapevine' information. Occasionally school teachers selected to test preliminary versions were used to help develop materials with modest success. The one project director who advertised for staff was disappointed in the results this tactic produced.

Staff members were used in various ways. Large projects tended to employ a few individuals full-time for periods of several years. Smaller projects either used part-time staff continuously for one to three years or confined development activities to summer vacation periods during which up to eight persons would be on the full-time payroll. Very small projects occasionally flourish even though staff members work only in their spare time and without compensation.

Only rarely did a project director claim that more than four persons contributed heavily to the final useable materials. As to the efficiency of the production process, opinions varied. Some project directors asserted that they could accomplish as much with far fewer staff members if they could select the most productive ones; others claimed that every staff member contributed substantially in some way even if not to the creation of high quality materials.

9.2.3 Advisory Groups and Materials Testing

The most common advisory-group structure reported involved two separate bodies. (1) A review board, consisting of scientists who are recognised as experts in the subject matter, which is charged with responsibility for the accuracy of the science content of the new materials. (2) A supervisory board, including project directors, trial users, school administrators and consultants, which determines operational policies. A few projects used more kinds of advisors and a few got along with a single (or in one case, no) Steering Committee.

The project directors' views on the value of advisory committees varied widely. Some asserted that their committees met often and gave valuable advice. Others admitted that advisors and consultants contributed little to the quality of the final materials and to decisions concerning operational procedures.

Every project director arranged for pilot tests of newly generated materials before putting them in final form. In a few cases, these tests were carefully planned and the results were thoroughly analysed using valid statistical procedures. More often the tests were conducted by a few staff members or their colleagues and the assessment of results was largely subjective. Nevertheless the testing did lead to revisions. Two complete revisions were reported by most project directors; one revision and three revisions were each reported by at least one project director.

9.2.4 Communication Channels with Prospective Users

Almost every project resorted to a newsletter as a primary method of disseminating information to prospective users. Another communication channel heavily relied on was the science teacher association journal. Some project directors also managed to attract the attention of the public press. Brochures, some prepared and distributed by the publisher, were used by several project directors.

Most project directors did not rely exclusively on the printed word to carry their messages; direct contact with prospective users was strongly advocated by several. Useful techniques included summer and in-service institutes, short workshops, visits to schools and talks at meetings of professional societies. Most, but not all, project directors distributed sample materials to potential users while the materials were still under development. Some pursued this form of advertising vigorously while others simply complied with requests. Some projects made use of 16 mm films professionally produced.

A question answered very differently by different countries is "who makes the decision to adopt or not to adopt new course materials?". In the U.S., such decisions are almost always made at the local school or school district level. At this level the decision is shared in different proportions among school boards, school principals, school faculties and individual science teachers. A respondent in the United Kingdom reported that the "decision lies between teachers and governors in privately financed schools, between teachers and local government advisory staff for publicly financed schools."

In Iraq, the secondary school curriculum is completely controlled by the Ministry of Education through special committees of university and secondary school teachers and ministry officials. The university curriculum used to be the sole responsibility of individual departments and colleges but in recent years national committees have been set up to make detailed recommendations which will probably bring the university curriculum as well under national control.

By contrast, in Pakistan the central government coordinates and stimulates the activities of the four provincial governments, each of which develops its own secondary school curricula which are introduced simultaneously throughout that province. Textbooks are published and other materials manufactured on a non-profit basis under provincial control. Heavy emphasis is placed on in-service teacher training, for which purpose Education Extension Centres have been established in each province.

Only a few project directors reported that the publishers of the final written materials played a large role in the promotion of the materials; most said this role was minimal and one even claimed the publisher made no contributions to promotion. Professional societies received only slightly higher ratings as aids to promotional efforts. Most of the positive comments in this context related to the traditional society roles of publishing written progress reports in their journals and providing a forum for oral reports at their meetings. It appears that societies rarely took a stand for or against adoption of particular materials.

9.2.5 Diffusion of Materials

The reports we received came largely from projects that had been in existence for about five years. In every case except one, the number of copies of the major text already distributed was more than one thousand and less than 30 000. Help, moral and substantive, in the diffusion effort came from numerous sources. Financial support for diffusion activities also came from various sources. Federal governments, universities, state governments and professional associations ranked on the top of the list of givers. Technical institutions, industry and science centres made small contributions to some projects.

Most project directors believe that prospective teachers of their new courses do need retraining before they will be prepared to use the new materials competently. Retraining is generally provided by the project in one format or another.

The answers to question E5 [11] of our survey were rather upsetting. One might expect that the number of adoptions would rise monotonically toward some target. This is the case in only about one-third of the reports we received. In another third, the curve of adoptions versus time peaked about two or three years after the materials first became available. Graphs for the other third show continuous decreases from some maximum number of adoptions reached soon after the materials were released.

9.2.6 Project Reports and Evaluations

Final reports, or even thorough progress reports, of course development projects are apparently fairly rare. Of the eleven responses we received to our survey, only three directors had submitted final reports. Of these only one had been published; the other two are available from the project directors.

We expected descriptions of evaluation procedures to occupy a major portion of this chapter. They do not, largely because evaluations are not generally performed; when they are, the reports are hard to come by. Among the eleven responses we received, seven reported that some sort of evaluation had been performed; of these only four reports were available and only two of these had been published in the literature. In most cases the evaluations consist of questionnaires completed by students and/or teachers. Only two of these evaluations had been conducted by evaluators who were not regular project staff members. One tested for changes in student attitudes; three tested student performance on science tests using controls of some kind; the remainder were little more than collections of opinions.

9.3 STATISTICAL DATA ON COURSE DEVELOPMENT PROJECTS

Curriculum development effort is very unevenly distributed throughout the world. Most of the projects that have been described in the literature or reported to the director of the International Clearinghouse on Curriculum Development Projects at the University of Maryland, U.S.A., were organized in the United States or the United Kingdom. The data in the two tables below seem to document this assertion. However, these data should be interpreted with care. It is entirely possible that reports of projects in developing countries are not published in journals known to those who compiled the bibliography and the Clearinghouse report from which the data were taken.

The survey of literature on Physics Education prepared for the Edinburgh International Conference on Physics Education was searched for articles describing course and curriculum development projects. Among authors from the U.S.A., the United Kingdom and other countries, the distribution of relevant published articles among elementary school projects, secondary school projects, tertiary school projects and evaluation projects is as shown in Table 1.

	Primary	Secondary	Tertiary	Evaluation	Total
U.S.	0	52	90	30	172
U.K.	0	20	11	5	36
Other Countries	6	40	20	13	79
	6	112	121	48	287

Table 1

A similar analysis of the projects listed in the Eighth International Clearinghouse Report 1972 [12] yields the data shown in Table 2.

	Primary	Secondary	Tertiary	Total
U.S.	14	27	18	59
Other Countries	0	22	1	23
Total	14	49	19	82

Table 2

9.4 INTERPRETATIONS OF THE DATA

9.4.1 The Motivations of Curriculum Developers

New course and curriculum developers accomplish much because they have gleams in their eyes. Most new projects are not motivated by carefully collected evidence that there are unmet needs. They are usually not planned to correct specific proven defects in earlier courses. Individual scientists, or small groups of scientists, become disenchanted with current science teaching, they create a design for an improvement and they sell their ideas to those who must be convinced of a need for change if the new conceptions are to materialize and achieve acceptance. There is little evidence that new projects are planned in response to an identified need or developed according to an optimum or even a rational procedure.

While there are examples of projects planned and executed by committees, it is clear that science teachers themselves have more confidence in those projects that result from the impulsive actions of outstanding individuals. If better projects can be conceived and managed in a systematic and organized manner, we have yet to discover the rules that would guide this activity in an unambiguous way. However some useful hints are contained in an entertaining paper published by the MIT Education Research Center [13].

9.4.2 The Dissemination of New Materials

The dissemination of new materials has seldom progressed smoothly. There are undoubtedly many reasons. Curriculum developers, the only persons who have a strong vested interest in promoting their own materials, are much better at development than promotion. More important, needs do differ from institution to institution and country to country. Courses designed to serve the needs of one group will not be ideal in another environment. A single national course will not satisfy all teachers and all students. A course that is appropriate for large numbers of students in one country will usually not be equally meaningful to students in a different country.

9.4.3 The Evaluation of New Courses and Curricula

In general, evaluation has been seriously neglected. To date, very few project directors have arranged for objective and controlled assessment of the degree of success their materials have achieved. There are several possible reasons for this. A major reason is that valid evaluation is difficult and expensive. Another is that developers are usually natural scientists while evaluators are usually social scientists; the two groups do not always trust each other. A third reason is that new projects often adopt novel goals and therefore comparisons between new and traditional courses, using any single evaluation instrument, may have little validity. Finally, few projects are as successful as the developers hope they will be and it may seem likely to the developer that an evaluation conducted by an objective observer will only produce disappointing results.

9.4.4 Trends Toward Smaller Projects

Over the years since PSSC set the tone for the development of new courses, the number of large course projects – at least in the USA – has peaked and is now declining. One obvious contributing factor is the increasing difficulty of obtaining funding for large projects. However, we believe the trend toward smaller projects is also a response to a clearly identified truth: problems differ from place to place and time to time, so solutions must be sought separately in each locality and repeatedly as time passes.

In many countries other than the USA, schools and universities are not autonomous and their courses are constrained by the requirements of a public examination system. Hence individual course development efforts tend to be fewer even though desirable. On the other hand, in some countries, particularly developing countries, course development is often aided by the government. In such cases the innovation often comes as a package involving new teaching approaches and new textbooks in a number of disciplines, new laboratory materials and programmes for the orientation of the teachers. The package may have a greater viability than a single course change unaccompanied by suitable equipment and provisions for teacher training.

9.5 RECOMMENDATIONS

1. Before embarking on curriculum and course reform, the innovator should be clear as to *why* the reform is needed. Possible reasons are: (1) expansion of the subject, (2) changes in employment patterns, including the needs of teachers, (3) changes in student wishes (perhaps broader courses, courses that allow self-expression, and courses making reference to technological changes, particularly those of the local society), (4) changes in the ability range of the students who study physics, (5) adaptation of courses to other cultures and to other student populations, (6) the development of new courses for new institutions, (7) the needs of the nation as perceived by the government or the people. In addition, school programmes might need to be developed to take

into account differences in teacher backgrounds and an increasing understanding of how children learn at different ages. As well as the above reasons, which may be broadly categorized as responses to external pressures, there are more personal reasons: (1) missionary zeal to do a better job and to attract 'converts', and (2) the desire to perform research into the process of education for its own sake.

2. There should be more consultation between the innovator and other interested parties. Faculty colleagues should be involved not only in deciding on course objectives but also in criticism of the method of teaching various topics. Some institutions have successfully mounted courses produced by teams of teachers. Students have been found by many to be active, discerning and helpful members of committees that undertake course design. Consultation with industrial employers is sometimes appropriate. At the school level, teacher participation is to be sought in order to increase the acceptability of the programme. Experienced psychologists, educational technologists and evaluation experts may be helpful. Service courses should be genuinely responsive to any needs specifically indicated by the departments to be served (chemistry, engineering, etc.).

3. It seems as though there will be increased need for physicists to offer courses for non-science students in universities. It is recommended that the subjects covered in such courses should concentrate on current problems, topics that professional physicists find exciting at present or social problems to which experiment and quantitative thinking can be applied.

4. Comparison of large curriculum innovation efforts with small ones shows complementary strengths and weaknesses. Large efforts can change the entire context of education in a nation or region and may produce higher quality materials. It is unlikely, however, that any one nation should encourage a proliferation of large expensive projects. There is, on the other hand, always a case for encouraging small efforts. They are more easily controlled and fitted to the local needs, and they help the development of teacher confidence and initiative. It is recognised that in some countries teachers are hard-pressed and have little time or resources. Such teachers should be encouraged to make use of materials and ideas generated by large projects, but they should always be prepared to select them with care and to adapt them to local conditions.

5. International organizations, governments and other national bodies should stimulate teachers to create materials by offering support for local course and curriculum development efforts. In addition, support from university faculty and from professional societies is often crucial.

6. The effects of new course materials should be assessed thoroughly by objective evaluators before materials are produced and used on a large scale. However, while the process of creative curriculum development will usually have salutary effects on instruction, one must not expect that new course programmes will always produce marked improvements in student learning. Very good results can be obtained by exploiting the enthusiasm of the developers, but these effects are usually local in space and time. While optimism about what can be done should continue unabated because this results in real benefits of its own, hard evidence that any specific new course is superior to the one it replaced is usually non-existent, in fact, it may be impossible to obtain.

7. Teachers should be encouraged to obtain feedback on their own courses. This can be done in several ways: (1) the use of participant observers, (2) discussion with students, (3) pre- and post-tests, (4) student performance in continuous assessment, (5) confidential questionnaires issued both during and after the course in which students anonymously comment on the difficulty and interest of the course.

8. Large projects might be encouraged to produce their materials in a form that lends itself to the creation of small modules which can be selectively accommodated to local needs in many different regions.

9. Innovators should take into account the fact that changes they introduce in their own courses can have repercussions on the teaching of related subjects and even on the curriculum as a whole. Changes should only be undertaken in consultation with the teachers and administrators likely to be affected.

10. All innovators should be aware of the variety of channels through which knowledge of their activities can be made known to a wider audience. Some of these are: (1) professional society meetings, (2) journals, (3) conferences, (4) textbook publishers and equipment manufacturers.

9.6 REFERENCES

1. *High School Physics Teaching: A Report on Current Practices*, American Institute of Physics (1972).
2. Welch, Wayne W. "Some Characteristics of High School Physics Students: Circa 1968". *J. Res. Sci. Teach. 6*, 242 (1969).
3. Welch, Wayne W. "Correlates of Course Satisfaction in High School Physics". *J. Res. Sci. Teach. 6*, 54 (1969).
4. Welch, Wayne W. "Physics Enrolments and Grading Practices". *J. Res. Sci. Teach. 6*, 44 (1969).
5. Welch, Wayne W. "Review of the Research and Evaluation Programme of Harvard Project Physics". *J. Res. Sci. Teach. 10*, 365 (1973).
6. Lewis, John L. *Teaching School Physics.* Penguin, Harmondsworth, U.K. (1972).
7. Brandt and Price. *Am. J. Phys. 42* (1974).
8. King, J.G. *Am. J. Phys. 34*, 1058 (1966).
9. *PSNS Final Report* (available from the AIP Information Pool, P.O. Box 617, Stony Brook, NY 11790, U.S.A.).
10. Black, Griffith, and Powell. *Physics Education. 9*, 18 (1974).
11. See copy of survey in the Appendix.
12. Lockhard, David. *Eighth International Clearinghouse Report 1972.* Science Teaching Center, University of Maryland, U.S.A.
13. Taylor and Zacharias. *ERC Occasional Paper No. 11.* Massachusetts Institute of Technology.

9.7 BIBLIOGRAPHY

Lewis, J.L. *Teaching School Physics Books*, Penguin, Harmondsworth, U.K. 1972.

New Trends in Physics Teaching, vol. I (1965–66), edited by W. Knecht for Unesco.

New Trends in Physics Teaching, vol. II (1970), Unesco.

Gillon, P. and H. *Science and Education in Developing States*, Praeger Publishers, New York 1971.

A Survey of the Teaching of Physics at Universities, Unesco 1966.

Teaching Physics Today, OECD, 1965.

Teaching and Learning: An Introduction to New Methods and Resources in Higher Education, Unesco 1970.

Learning to Be: The World of Education Today and Tomorrow, Unesco, Paris 1972.

Journal Articles

Anderson, O.T. and Artman, R.A. "A Self-Paced, Independent Study, Introductory Physics Sequence – Description and Evaluation". *Am. J. Phys. 40,* 1937–1972).

Arons, A. "Educational Practices – An Expert View of Current Trends". *Phys. Teach. 11,* 487 (1973).

Baron, M. and deRansemberg, P.A. "Approach to a General Physics Course for Natural Science Students". *Am. J. Phys. 38,* 137 (1970).

Bolin, C., Ignatz, M. and Lewis, R. "Physics without a Teacher – A Model for Independent Study of the Project Physics Course". *Phys. Teach. 11,* 469 (1973).

Bongarzone, E.J. "Citizen's Science: Teaching the Man-Made World". *Sci. Teach. 37,* 57 (1970).

Bowman, L., Nelson, T., Stevens, J., Svingen, T., Hein, D. "A New Under-Graduate Programme for Future Physics-Chemistry Teachers". *J. Coll. Sci. Teach. 1,* 47 (1971).

Butler, L. and Inoue, K. "Media Programmed Learning Systems". *Phys. Teach. 10,* 20 (1972).

Butzow, J.W. and Pare, R. "Physical Science: A Multi-Media Facilitated Course". *J. Coll. Sci. Teach. 2,* 29 (1972).

Calame, G.R. "The Science in Science Fiction: A Seminar Course". *Am. J. Phys. 41,* 184 (1973).

Calandra, A. "Science for Nonscience Majors". *J. Coll. Sci. Teach. 1,* 35 (1972).

Carlson, E.A. "Teaching by Television: A Critique". *J. Coll. Sci. Teach. 2,* 15 (1973).

Cothern, C.R. "Teaching Science to Nonscience Majors – Some Attitudes, Ideas, and Approaches". *Am. J. Phys. 41,* 8 (1973).

DeRose, J.V. "Evaluation of Learning in Individualized and Self-Paced Science Courses". *Sci. Teach. 39,* 32 (1972).

Devonds, S. and Hartmann, L. "A History-of-Physics Laboratory". *Phys. Today. 23,* 44 (1970).

DiLavore, P. and Walker, J.D. "Physics for Teachers: An Experimental Course". *Phys. Teach. 9,* 370 (1971).

Donnelley, D.P. "The Atmosphere and the Ocean: A Field Study Course". *Am. J. Phys. 41,* 664 (1973).

Editorial, University Physics. *Nature. 241,* 146 (1973).

Editorial "A New Curriculum for the Schools?" *Nature. 243,* 49 (1973).

Eger, M. "Physics and Philosophy: A Problem for Education Today". *Am. J. Phys. 40,* 404 (1972).

Elliott, W.E. "Experiences with Self-Paced General Physics Courses". *J. Coll. Sci. Teach. 2,* 35 (1973).

Fogel, A. "A Course in Modern Physics for Columbia". *Am. J. Phys. 38,* 806 (1970).

Franklin, A.D. "Physics for Educationally Disadvantaged Students". *Am. J. Phys. 41,* 3 (1973).

Friedman, C.P. "A Model for Improving 'Advanced' Courses in Physics". *Am. J. Phys. 40,* 1602 (1972).

Friedman, C.P. and Strickland, J.S. "Individualized PSSC College Physics". *Phys. Teach. 11,* 300 (1973).

Fruscione, A.A. and Richards, S.F. "An Alternative to Conventional Classroom Structure". *Sci. Teach. 37,* 27 (1970).

Gard, P.E. "ECCP and the Urban Student: An Activities Approach". *Phys. Teach. 10,* 459 (1972).

Gardner, P.L. "Deterioration of High School Students' Attitudes to Physics". *Nature 250,* 465 (1974).

Gerson, R. "Experience with an Environment-Related Physics Course". *Phys. Teach. 11,* 236 (1973).

Giancoli, D. "A Course in Biophysics. An Integration of Physics, Chemistry, and Biology". *Am. J. Phys. 39,* 739 (1971).

Goar, F.D., Fentem, D.G., and Bushman, G.L. "The Moline Plan for Increasing Physics Enrollments". *Phys. Teach. 8,* 241 (1970).

Green, B.A. Jr. "Physics Teaching by the Keller Plan at MIT". *Am. J. Phys. 39,* 764 (1971).

Hare, M.G. "Environmental Physics – A Course". *Am. J. Phys. 41,* 956 (1973).

Harvey, T.J. and Page, R.L. "Training Science Teachers in Methodology". *Nature 245,* 75 (1973).

Hecht, E. "Physics Zero – A New Approach for the Nonscience Major". *Phys. Teach. 11*, 490 (1973).

Hernandez, C. and Rushby, A. "A New Course for Physics Teachers in Peru". *Phys. Teach. 11*, 401 (1973).

Herr, L.G. "Unified Science: A Solution to Physics Enrollment". *Phys. Teach. 9*, 248 (1971).

Hewitt, P.G. "Conceptual Physics. Turning Nonscience Students on to their Everyday Environments". *Phys. Teach. 10*, 515 (1972).

Hodges, L. "A Course on the Physics and Chemistry of Pollution". *Am. J. Phys. 39*, 935 (1971).

Huque, A.O. "Pakistan Builds Science Program for High Schools". *Sci. Teach. 37*, 73 (1970).

Jirgal, G.H. Jr. "A Computer-Assisted Course in Intermediate Mechanics". *Am. J. Phys. 40*, 437 (1972).

Johns, R.H. "Gymnasium Physics". *Phys. Teach. 9*, 308 (1971).

Joyce, R. and Kearney, P. "Individualized Science Program". *"Sci. Teach. 39*, 45 (1972).

Julian, G.M. and Stueber, A.M. "Physicist + Geologist → Geophysics Course". *Am. J. Phys. 42*, 556 (1974).

Kahn, P.B. "A New Degree Program in Physics". *Am. J. Phys. 39*, 1535 (1971).

LaBrecque, R.J. "Individualized Project Physics for High Schools". *Phys. Teach. 11*, 301 (1973).

Le Marne, A.E. "Evaluation of a Group Controlled Audio-visual System of Learning". *Physics Education, 7*, 218 (1972).

Liao, T. and Piel, E.J. "Let's Get Relevant". *Phys. Teach. 8*, 74 (1970).

Lietz, G.P. "Light, Color, and Photography: A Course for Artists and Others". *Am. J. Phys. 41*, 953 (1973).

Liming, F.G. Jr. "A Topical Approach to Astronomy for Nonspecialists". *Am. J. Phys. 40*, 1575 (1972).

Marston, E.H. "A Course on the Physics of Urban and Environmental Problems". *Am. J. Phys. 38*, 1244 (1970).

McClelland, G. "Physics Education in Ghana". *Phys. Ed., 7*, 341 (1972).

McDonald, P.F. "Acoustics for Music Majors – A Laboratory Course". *Am. J. Phys. 40*, 562 (1972).

McFarlane, W.K. "A Discriminating Laboratory in Elementary Mechanics". *Am. J. Phys, 38*, 305 (1970).

McGuire, J.H. "Teaching Cultural Physics to Texas Aggies". *Am. J. Phys. 40*, 1587 (1972).

Meyers, J.T. "Old Physics Taught a New Way". *Phys. Teach. 9*, 245 (1971).

Morgan, M.G. "Topics in Technology and Modern Social Problems – A New Course for Science Students". *Am. J. Phys. 40*, 116 (1972).

Moyer, A.E. "Don't Never Plant Corn on the New of the Moon". *Phys. Teach. 9*, 168 (1971).

Mumsee, J.H. "An Evaluation of a Nonlecture Technique in the Teaching of Physics". *Am. J. Phys. 40*, 1119 (1972).

Onn, D. G. "A 'Medical Physics' Course Based Upon Hospital Field Experience". *Am. J. Phys. 40*, 1147 (1972).

Pallrand, G.J. "An Introductory Physical Science Course: Time, Space, and Matter". *Phys. Teach. 8*, 124 (1970).

Parker, R.H. and Whittles, A.B.L. "Introduction of Special Physics Topics (Geophysics) through the Use of Physics Laboratory Projects". *Am. J. Phys. 38*, 65 (1970).

Perry, B. and Miller, C. "A Unified Approach to Introductory Physics Based on the Conservation Laws". *Am. J. Phys. 38*, 1028 (1970).

Philippas, M.A. and Sommerfeldt, R.W. "Keller vs. Lecture Method in General Physics Instruction". *Am. J. Phys. 40*, 1330 (1972).

Physics Education Vol. 7, 66, Feb. 1972.

Pickar, A.D. "Core Course for Science Majors Combining Material from Physics, Chemistry and Biology". *Am. J. Phys, 38*, 255 (1970).

Pollard, E.C. "Physics for the Nonscientist". *Phys. Teach. 8*, 11 (1970).

Prescott, J.R. and Anger, C.D. "Team-Teaching Freshman Physics". *Am. J. Phys. 40*, 311 (1972).

Prescott, J.R. and Anger, C.D. "Removing the 'Cook Book' from Freshman Physics Laboratories". *Am. J. Phys. 38,* 58 (1970).

Puri, O.P. "Cooperative General Science Project – A Progress Report". *Phys. Teach. 9,* 320 (1971).

Redfield, D.D. and Darrow, S.P. "ISCS Intermediate Science Curriculum Study". *Phys. Teach. 8,* 1970 (1970).

Roeder, J.L. "A Humanistic Approach to Science". *Am. J. Phys. 40,* 1615 (1972).

Rossing, T.D. "Physics for Musicians". *Am. J. Phys. 39,* 1480 (1971).

Roxas, Segundo V. "Formative Evaluation of the Teacher's Guide in a High School Physics Course Developed by the Science Education Centre, U.P.", University of Colorado, Boulder, Colorado, U.S.A. (1974).

Sandin, T.R. "An Inexpensive Audio-Tutorial System". *Phys. Teach. 11,* 172 (1973).

Schmidt, S.A. "Science Fiction Courses: An Example and Some Alternatives". *Am. J. Phys. 41,* 1052 (1973).

Schwab, T.J. "The Option-Filled Laboratory". *Phys. Teach. 11,* 111 (1973).

Sherwood, M. "Educational Innovators". *New Scientist* Vol. *58,* no. 849, 610 (1973).

Shonle, J.I. "A Progress Report on Open-Ended Laboratories". *Am. J. Phys. 38,* 450 (1970).

Sneider, C. "A Laboratory and Discussion Approach to High School Science Teaching". *Phys. Teach. 9,* 20 (1971).

Soluokhin, R.I. and Belyaev, S.T. "Restructuring Higher Education". *New Scientist* vol. *58,* no. 844, 274 (1973).

Soxman, K.A. "Mini Physics at South Missouri State College". *Phys. Teach. 10,* 339 (1972).

Tan, B.T.G. "A New Electronics Course for Physics Students". *Am. J. Phys. 38,* 1169 (1970).

Uritam, R.A. "War, Peace, Science, and Technology in the Atomic Age – A Physics Course for the General Student". *Am. J. Phys. 40,* 1324 (1972).

Uritam, R.A. "New Directions in Physics Education". *J. Coll. Sci. Teach. 2,* 23 (1972).

Uritam, R.A. "Mini-Courses in Physics". *J. Coll. Sci. Teach. 3,* 137 (1973).

Welch, W.W., Walberg, H.J. and Ahlgren, A. "The Selection of a National Random Sample of Teachers for Experimental Curriculum Evaluation". *Sch. Sci. Math. 69,* 210 (1969).

Welch, W.W. "Correlates of Course Satisfaction in High School Physics". *J. Res. Sci. Teach. 6,* 54 (1969).

Welch, W.W. "Evaluation of the PSNS Course. I: Design and Implementation" and "II: Results". *J. Res. Sci. Teach. 9,* 139 and 147 (1972).

Welch, W.W. "Review of the Research and Evaluation Program of Harvard Project Physics". *J. Res. Sci. Teach. 10,* 365 (1973).

Wentzel, D.G. "Science Education: A Case for Astronomy". *Am. J. Phys. 39,* 27 (1971).

Wigley, E.J. "The Technological Approach". *Phys. Teach. 10,* 8 (1972).

Wissink, M. "Curriculum Revision – A New Approach". *Phys. Teach. 11,* 355 (1973).

Zeilik, M. II "Astrology in Introductory Astronomy Courses for Nonscience Specialists". *Am. J. Phys. 41,* 961 (1973).

Zetterholm, E.E. and Remington, L.D. "Different Goals, Different Methods". *Sci. Teach. 41,* 19 (1974).

9.8 APPENDIX

Questionnaire for a survey of curriculum development projects

The following questions were prepared as a means of collecting information about course and curriculum development projects. The information obtained was used in the preparation of the paper on which this chapter is based.

A. Project Origins

1. Did the idea and organizational efforts that led to the organization of your project originate with potential student users, their teachers, academic scholars other than the teachers of potential student users, academic administrators, nonacademic individuals or groups, or persons in some other category of educators?

2. What primary motivating factors were responsible for the large amount of energy invested in this project by the project organizers and directors?

3. Was early support provided by some organization or institution, and was this support essential to the organizational efforts?

4. What earlier curricula (e.g., PSSC, Nuffield) have influenced your curriculum, and to what extent?

B. Selection and Utilization of Staff

1. What tactics were used to identify productive project staff members? Do you regard these tactics as unusually successful?

2. During what time periods did staff members characteristically contribute to the development of project materials: (1) full time for one or more years; (2) full time during summers only; (3) part time during one or more calendar or academic years; (4) some combination of the above; (5) some other time periods?

3. Was most of the successful development accomplished by a few individuals or did many persons make major contributions?

4. What fraction of those persons who served on the production staff actually produced materials that survived editorial procedures substantially unchanged? What fraction would you hire again if you were directing a similar project on a very tight budget?

C. Advisory Groups and Materials Testing

1. What kinds of advisory structures were created to assist the project director in establishing policy and reviewing preliminary materials?

2. What kinds of responsibilities did these advisory groups accept, how often did they meet, and how effectively did they function?

3. What kinds of arrangements were made for classroom testing of preliminary editions of materials?

4. How often were your materials revised and to what extent were the nature of these revisions influenced by feedback obtained from classroom testing?

D. Communication Channels with Prospective Users

1. What methods, such as newsletters and announcements in journals, did you use to alert prospective users to the availability of your materials?

2. Were preliminary versions of your materials made available on request to prospective users? If so, how many users were accommodated in this way?

3. Please describe your promotional efforts designed to secure adoptions. Did you hold workshops and briefing sessions for prospective users? Did you contact ministries of education and supervisors of school districts to discuss adoption possibilities? (I am particularly interested in who made the final decision to adopt or not to adopt in each nation or school district you contacted.)

4. What role did the publishers and distributors of the final versions of your materials play in the promotion of your materials?

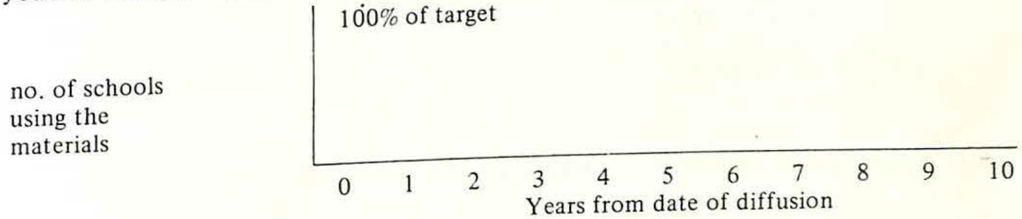
5. What role did professional societies and international organizations play in the dissemination of information about your materials?

E. Diffusion of Final Materials

1. Approximately how many copies have been distributed to the types of institutions for which the materials were intended?

2. How much support and encouragement have you received from
    - (a) the government?
    - (b) universities?
    - (c) technological and technical institutions?
    - (d) professional associations?
    - (e) science or teachers' centers?
    - (f) industry?
    - (g) others?

    (If any of these have been actually obstructive, it would be helpful if you could indicate this.)
3. What non-print resource materials, integral to the curriculum, have been made widely available?
4. Is re-training of curriculum users considered necessary for proper use of the materials? If so, please estimate the rate of re-training and give some indication of how this number relates to the total target. What sort of organizations provided and arranged the re-training?
5. The rate at which schools adopt the programme is not always positive since some schools may subsequently abandon it. It would be most helpful if you could guess at the form of the graph that might result if you had the data to plot it (do not attempt to be precise).



Add any comments you can that would explain the form of the graph.

F. Project Reports and Evaluations

1. Was a complete final report of project procedures prepared and if so, how can a copy of this report be obtained? (Please send a copy if that is convenient.)
2. How widely have project reports been disseminated? Have they been published? If so, where?
3. Was a formal evaluation conducted to determine the extent to which project goals were achieved? Was this conducted by project staff or independent evaluators?
4. What evaluation techniques were employed?
5. How widely have evaluation reports been disseminated? Have they been published? If so, where?

G. Characteristics of your country

1. Give a brief statement of the national goals as seen by the country's statesmen (insofar as that they are of concern to educators).
2. Briefly outline the nature of the educational system in the countries, regions, or areas relevant to your project.
3. In relation to 1 and 2 above, give a brief statement of your perception of the needs and priorities which were of concern in designing and implementing your curriculum.

10 Diffusion of innovations in physics education into national systems

Fifteen years after PSSC exploded on the world, it is rare to find a country which is not involved in science curriculum innovation. The features of the innovations are as various as the countries. Each project, such as PSSC, Nuffield Physics and Project Physics, had a unique contribution to make to the teaching of physics, but it was a contribution for a particular society. Since the goals of different curricula are not the same there is no reason why one project should be suitable in a different social setting. It is therefore unlikely that any course has been successfully adopted in its entirety in other countries. When a country decides on innovation, those concerned usually examine material from other countries and then decide whether to create from the beginning or to adopt and adapt. Ultimately it will be necessary to implement the new programme and this chapter, based on an original paper by Judith Reay, examines some of the strategies used in achieving large-scale implementation.

10.1 NATIONAL SUPPORT FOR CURRICULUM REFORM

There are a number of sectors of society which are likely to concern themselves with the introduction of curriculum reform. The degree of centralization varies, but in all countries ministries of education are likely to be involved to some extent. Ministries can be as helpful or as obstructive as they choose.

The government was an active participant in curriculum design in New Zealand, where school inspectors shared the writing with teachers [13, p324]. In England, the Ministry of Education and the inspectorate were not involved in the development of the Nuffield projects, but in Scotland the Scottish Integrated Science team received support from the central government and the inspectorate from the beginning. In East Africa, the Ministries of education in Kenya, Tanzania and Uganda initiated the School Science Project (SSP) with international cooperation. A different situation is seen in the United States where the National Science Foundation (NSF) funded large projects such as PSSC, Project Physics and the Integrated Science Curriculum Study (ISCS), but Hurd [9] describes how the NSF was anxious to avoid any suggestion that it was trying to direct the curricula of schools. The task initially was limited to 'course content improvement' and the implementation of reform was apparently left as a local matter [9, p66, 99].

Although innovations in tertiary education itself have been few, university scientists have very often become deeply involved in curriculum reform. The universities may initiate a project, as happened with Harvard University and Project Physics, Florida State University and ISCS, and the University of the Philippines in their curriculum reform project. The desire of PSSC to achieve academic excellence led to the establishment of a development team of outstanding university scientists and the result was an immensely valuable course, ideas from which have served all later projects. But by 1963 a change was noticeable in the views of the NSF, and the US Office of Education declared at an international meeting that there was a need for greater involvement of teachers [6, p63–66]. Teachers were heavily involved in their later projects, Project Physics and ISCS [3 and 18]. In the Philippines there was close understanding between school and university and in the Nuffield projects there was a particularly happy partnership between the university scientist and the school teacher [6, p67–74].

Industry can play a valuable part in overcoming some of the difficulties encountered in curriculum reform. Together with universities and technical activities centres, industry can help in the design and manufacture of apparatus. Good examples of such cooperation can be found in India, Kenya, Lebanon, Mexico, the Philippines and Turkey. In such projects as PSSC and Nuffield, commercial manufacturers collaborated closely with the organizers.

Industrial concerns have a vested interest in the scientific preparation of young people. One example of the help they can give to implementation of new programmes is the set of films for teachers financed by Esso Petroleum for Nuffield Physics: these films introduce teachers to new apparatus, giving them confidence in its use in the classroom.

Science teachers' associations have not been much concerned in curriculum reform until recently. The United Kingdom is exceptional since its Association for Science Education (ASE) was much involved in the initiation of the Nuffield projects [13, p304]. Its meetings and publications have also been most influential in the diffusion process. The Science Teachers Association of Nigeria is involved in the actual development process and is reaping royalties from its integrated science course which enable it to plan further developments.

Examining boards, where they exist, can play an important part in curriculum reform. They can impede development; they can, on the other hand, be a powerful influence assisting reform, as has been repeatedly stressed by Professor Eric Rogers [21]. Nuffield [6, p73], SSP [12, p50] and the New Zealand project [13, p326] all worked closely with examining bodies. By contrast, India attempted to introduce the PSSC course without changing the form of traditional examinations with unfortunate results. CHEM Study is in difficulty in Western Australia for the same reason.

Teacher education establishments and teachers' centres all have an intimate interest in curriculum reform and can certainly play a large part in diffusion of information about development work [3, 5, 7, 14, 15, 19, 20 and 22]. Finally one must not forget the communications media, whose help can certainly be solicited in the diffusion process. In fact all the sectors mentioned above can play a valuable part in this process.

10.2 WHAT HAS HAPPENED TO THE BIG PROJECTS?

PSSC is now fifteen years old. In high schools in the United States it is giving way to Project Physics although it is still much used at college level. It had considerable influence overseas in such countries as Greece, Israel, Italy, New Zealand, Norway, Spain, Sweden, U.K., Venezuela and Yugoslavia [13, p311, 323]. Even if this is simply because there was nothing else available in 1961 when a course was needed, it does say a lot for PSSC that it has continued to flourish for so long. India introduced PSSC without ensuring that certain conditions were satisfied (such as motivated and re-oriented teachers) and without considering local circumstances. The advance on earlier teaching was too great and PSSC did not survive as such in India, although some parts of the package are still used, such as the locally manufactured kits of apparatus and the films. Mexico was only partially successful with PSSC, which proved useful at college but not high school level.

The humanistic flavour of Project Physics is likely to have growing appeal, at least to teachers as they come more and more to recognise a need to put a greater *affective* component into their teaching. The multimedia approach will be welcomed in some situations and will be highly unpopular in others, probably depending on the relative shortage of teachers or of money. The Philippines project is mostly based on Project Physics, although much of the multimedia element has been eliminated: there has been a massive national effort which has helped achieve success. Japan is piloting a modification. Australia and New Zealand undertook a modification and its introduction has been followed by a rapid rise in the number of schools using it (3 to 165 in four years). The enrolment of girls in physics increased by 300 per cent among those who had followed the course. In the United States, the directors of Project Physics were able to report in 1972 "Project Physics is a success . . . . on many different criteria, at least one educational innovation has achieved most of its intended effects . . . . The evidence . . . . is empirical, statistical, clinical, and anecdotal" [28].

In England, some half of eligible schools appear to be following the full Nuffield course or using its materials [29] and 22 per cent of the O-level physics candidates in 1974 entered for the Nuffield papers. The more recently published Nuffield A-level project is being adopted widely. Nuffield Combined Science is being used by some 30 per cent of eligible schools. The School Science Project (SSP) in East Africa is a descendent of Nuffield physics and nearly half of all candidates in Kenya for the EAEC physics examination in 1972 were using it [12, p51].

ISCS claims that it is now taught to hundreds of thousands of children [3] and since it was published only some four years ago it seems that the designers achieved the massive impact for which they aimed.

10.3 PROBLEMS AND CHALLENGES

The stages in successful diffusion of a curriculum may be set out as follows:

(i) The teachers hear about it.

(ii) The teachers like it.
They feel it meets a need and suits the pupils and conditions.

(iii) The teachers feel they can teach it.
They believe they will not feel insecure or incompetent in doing so.

(iv) The teachers believe they will be helped to teach it.
They believe there will be support from central government, science centres or teachers' centres, etc.

(v) The teachers choose to teach it (or the teachers *willingly teach it* if the educational system is a centralized one which denies the teacher freedom of choice).

It is not possible to reach stage (v) without going through all the other stages in order and the process is a rather slow and deliberate one. Very often bureaucracies fail to realise this and stage (i) may be accomplished by the arrival of a box of materials from the Ministry. Hardly a strategy for good implementation!

10.3.1 Whatever Happened to Nuffield Junior Science?

It might be interesting to look at one particular case, the Nuffield Junior Science project. The Director has described how the project faded into a few isolated cells of activity [26]. Clearly stage (v) was not reached.

What happened about stage (iv)? The project lasted for only three years and after that there was no one around to help teachers. In one respect the project was outstandingly successful because it initiated the teachers' centre movement in the U.K., but at that stage the staff at the centres were probably inadequate to look after a thousand teachers. Stage (iv) was not reached.

Stage (iii) then? Primary school teachers are scared of science, and the teachers' guides for this course were most unstructured. The teachers were afraid of an unpredictable teaching-learning situation in a 'hard' subject, although the project team believed that their methods were the very ones which would solve the problem. They seem to have been wrong.

Probably not even stage (ii) was reached. There were repeated pressures to provide work cards and kits and the director, G.R. Wastnedge, says "we resisted the pressure": He should have known that shotgun weddings rarely work. For teachers to 'like' a course they must understand and accept its philosophy. *Science 5–13* is a project which picked up where Junior Science left off, and began by stating objectives to help give teachers this understanding.

For Nuffield Junior Science it is even in doubt if stage (i) was achieved. The staff consisted of one organizer for three years and six other people for two years or less. Preparing, testing, revising and publishing materials while working with a thousand teachers in nearly fifty areas could hardly have left much time for telling the nation about it!

The conclusion is that the project was too small; lasted for too short a time; the staff was too unwilling to compromise its ideals; and they took on too much.

10.4 SUGGESTIONS FOR ACTION

It is axiomatic that planning for implementation should begin at the moment of conception of the project. Although we shall examine each of the stages (i) to (v) in order, *planning* for them has to proceed simultaneously.

10.4.1 Stage (i): Giving the Teachers Information

A co-director of Project Physics believes that in the beginning survival counts. Curriculum innovation should be introduced quickly in a way that shows it off, or there will soon be loss of interest [22, p557]. Most NSF funded projects issue newsletters [17, p38]. Some projects do not believe in free dissemination of the trial materials until they have been shown to work effectively, and Nuffield angered many by its secrecy over its trial materials. Conversely, a conference in Montevideo (although not quite in the same context) recommended the dissemination of materials from the various work groups: the objectives and evaluation procedures, the units, the banks of test items, the papers that never get into final print, and nearly everything else [25, p94–96]. As ISCS found out, large development teams are valuable for public relations [3] and it makes good sense to train teachers to diffuse the innovations. Project members can contribute to journals and area meetings can be held, while Government information services are usually willing to arrange radio or television interviews. An information officer or PRO would be invaluable to a project. Meanwhile the headquarters team needs feedback about the extent of changes in teacher behaviour, although this is difficult to obtain on a large scale. During trials of the Introductory Physics Course (F-NUN) in Slovenia, Yugoslavia, teachers' attitudes were surveyed after one year with the following results: 60 per cent were willing to cooperate further under the same conditions as before; 30 per cent were willing to cooperate conditionally if there were a better supply of teaching aids, if there were less work and if there were more pay; 10 per cent were not willing to cooperate any longer (mainly for personal reasons). The project has been comparatively successful in collecting other feedback and for this it paid small sums of money.

10.4.2 Stage (ii): Giving the Teachers what they WILL Like

This is not necessarily the same as 'what they ask for' or what they think they would like.

Finding out in a pre-project survey what a cross-section of the nation wants is a first step towards getting the country on the side of the new curriculum. This helps towards stage (ii), but also stage (iv). Kerr reported some research done on the aims selected by educators in developing countries and the results turned out to be very different from those in the U.K., especially in having an affective component higher than the cognitive one. The development of society was desired rather than development of the individual. From another point of view, an engineering professor from Sierra Leone points out that in tertiary education an emergent country often has to settle for the graduates it needs rather than those it would like to have, that is, technicians rather than technologists [24]. Sheila Haggis has written of consulting the wise men of the village [8].

Another strategy is to provide attractive materials for the teacher. This was used in Project Physics, in Estudios Libres in Venezuela and, in a different way, by the Australian Science Education Project (ASEP). These collections contain units from which a variety of courses can be built up, and in this way the tendency of teachers to reject complete packages has been overcome. In Nuffield Combined Science, the teacher is asked to chart his own route through the concepts, and the number of degrees of freedom offered by such approaches should perhaps vary with the level of knowledge and experience of the teacher.

In the little ASEP booklets, the Piagetian stage for each unit is indicated; otherwise the curriculum is wholly flexible so that the teacher may use as few or as many units as he wishes, with or without another curriculum. The hypothesis is that the teacher will gradually progress from his old comfortable curriculum to an increasingly more exciting ASEP one and so stage (iii) (confidence) would be reached. Project Physics has a variety of options, which would be very stimulating to the creative teacher but might be a little frightening to the insecure teacher.

To the teacher, the most familiar and easily appraised element of the curriculum package is the textbook, since this has often been his only curriculum guide. He has developed a means of working with a textbook and he does not know how to work without one. Teachers are slow to adopt curricula not associated with a textbook; if they like a textbook they are fairly ready to adopt the whole curriculum package, finding out what it is all about while using it.

10.4.3 Stage (iii): Giving the Teachers Confidence

This is probably the toughest nut of all to crack as widespread lack of confidence lies at the root of so many bad teaching practices. It is likely that PSSC would have been more acceptable in high schools if it had been closer to existing practice in schools. The West Indies Science Curriculum Innovation Project (WISCIP) of Trinidad was developed by a most imaginative teacher educator who, after determining the level of perception of the teachers, adapted Scottish Integrated Science as a more formal course closer to their experience [27]. It was not very long before the teachers themselves recognised the need to move WISCIP back towards the Scottish Course, and so the first version served its purpose.

F-NUN of Yugoslavia uses a strategy of gradual involvement with the following stages: (a) introductory course, (b) teacher decides whether to take the teaching package, (c) after one month he decides whether he will cooperate by criticising the text and teacher's guide, (d) after two months he decides whether he will cooperate by preparing, for extra pay, five class experiments during the year, (e) throughout the year he decides whether he will cooperate in a local group by preparing a teaching package.

Participants are not pressed for unreasonably quick decisions as measurements have been made of average reaction times of teacher, school and local education authority. Positive reinforcement is considered important and everyone who decides to participate *must* be successful. The headquarters team or outside circumstances are blamed if anything goes wrong, *never* the teacher. This is difficult to operate, however, and requires a lot of personal contact.

There should, of course, be continuous interaction among schools, training colleges and universities, and another means of giving teachers confidence is through teacher education. A sad fact is that many teachers are entering the new system trained in the old ways and clearly not enough teacher educators have been reached by the projects. The number of new teachers is small compared with the number of practising teachers, but it does seem to be a waste of the training period. Any effort from the innovators to reach all the teacher educators would be effort efficiently spent, because of its multiplier effect, a term that should be the watchword of the curriculum implementer. Getting the teacher educators on to the development team is crucial.

Rutherford and Keohane agree that the cost of re-education for a new curriculum will be many times larger than the development cost. Keohane stresses the need for an after-sales service and Rutherford says that no funding agency should consider a proposal unless it includes explicit plans for coping with the related teacher education problem [22, p556 and 13, p308].

A strong body of opinion holds that the numerous short courses have not been effective. An interesting recent development is the type of handbook put out by SCISP and ASEP (for example, *Getting to Know Integrated Science*). It is a sort of seminar programme/workbook and could be used in area meetings of a few days, or in self instruction.

However, any project whose continuing success depends on constant input from the headquarters team is at risk. ISCS has built teacher education into its books. Rutherford [22, p562] suggests an autotutorial approach, which would also be designed to reach the teacher educators. In fact, this is the basis of the methods used by the Unesco/UWI Teacher Training Project: each of its unit packages begins with educating the teacher educator and ends with educating the child, all in a self-instructional way [20, p82 and p201]. One would like to think that teacher education materials could be built into the curriculum package, but there is insufficient evidence that they really work and we must wait for a careful evaluation.

An effective way of giving teachers confidence and enabling them to appreciate the new curriculum is to let them make it. The in-service post-graduate teacher-education programmes of the University of the West Indies rely a great deal on this means of professional training. Much of the work produced is for O-level integrated science standard and, in a country whose teachers are very much single subject specialists, this is a formidable undertaking, especially when the emphasis is on the social impact of science. Yet the teachers find the experience very exciting. Even after a curriculum is developed, opportunities for teacher education in this way remain, especially if the package is composed of minicurricula. Teachers meeting in a teachers' centre can generate a steady supply of new units, revisions, and ancillary materials including items for the test bank. The headquarters team must face the need to edit units produced in this way.

10.4.4 Stage (iv): Giving the Teacher Support

Government supervisors, inspectors and education officers are supposed to exercise this function. A sympathetic and enthusiastic supervisor should not visit the teachers too often, but he can do much to untangle red tape and see that action is taken. It is the business of the project itself to see that he is (or remains) sympathetic and enthusiastic. This is often made effective by having an advisory committee to the ministry of education. Scotland's committee contains inspectors, staff from colleges of education, university staff and teachers.

Teachers will need the support given through provision of the right kind of apparatus to run the course. It is the role of the authorities to see that they get it.

A teacher will work well if he knows that the principal at his school is interested in, and approves of, the new curriculum. A project can gain much by providing seminars for such principals, especially if they are not scientists. Reaching parents is also important and should not be overlooked by a project.

Science centres have proved extremely useful in curriculum implementation, providing a loan service of apparatus and other resource material, giving a consultative service and providing opportunities for teachers' meetings and seminars [31].

10.4.5 Stage (v): The Teachers Implement the Programme

When the teachers have been helped through all the earlier stages, this stage takes care of itself.

10.5 CONCLUSIONS

The general implication is that there is a need to establish confidence. The teacher needs all the support he can get from influential sections of society, including his government, if he is to work as a creative professional in implementing a curriculum.

Curricula imported from other countries do not, as they stand, prove to be effective in a new setting. If a curriculum from elsewhere is to be modified, a cadre of the best people should come from the country which produced the programme, so that there is an extensive exposure to the parent course, leaving the door open for eventual rejection of that particular curriculum. It may be better for a country to produce its own curriculum, though it is wise to study the successes and failures of others.

Finally it must be remembered that adoption of a course into the schools does not complete the process. Curricula grow old quickly and it is essential to have continuous revision and diffusion, a process made easier if the course is composed of units.

10.6 ANNOTATED BIBLIOGRAPHY AND REFERENCES

1. Abruscato, J. Policy making in science education: a point of view. *Science Education 54* (1970) p. 69–70.

   Distinguishes between policy makers and curriculum builders, and suggests emphases in the goals set by the policy makers.

2. Brandou, J.R. Science education in two countries of the Far East – a firsthand view. *Science Teacher 37* (October 1970) p. 26–31.

   Part of the paper contains a brief history of science curriculum renewal in the Philippines.

3. Burkman, E. An approach to instructional design for massive classroom impact. *Journal of Research in Science Teaching 11*, (1974) p. 53–60.

The article by one of the initiators of ISCS is a valuable account of its processes of development and diffusion, which he believes were highly successful.

4. Chesley, R.E. and Roxas, S. High School physics curriculum development in the Philippines. *The Physics Teacher 10,* (1972) p. 128–131.

   A description by people associated with the project of the situation that led to it, and an outline of the project.

5. Cohen, R.G. Problems of "retreading" science teachers, part II. *Science Education 56* (1972) p. 417–421.

   Suggests a shift in the emphases of in-service courses from cognitive to affective activities (and concerns). He believes that the teacher should be considered as a vulnerable risk-taking human being who, when certain emotional needs are met, can become a creative, free, self-actualizing teacher.

6. Commonwealth Education Liaison Committee. *School Science Teaching.* London: HMSO, 1964. 140p. Report of a Conference at the University of Ceylon.

   Appendix II (p. 63–82) contains descriptions of recent experiments on the teaching of science, notably in USA and the United Kingdom; the entry for Europe suggests that there was little radical innovation at that stage.

7. Geisert, P. Performing a problem survey – data for educational change. *Science Education 57* (1973) p. 533–538.

   Describes a strategy for analysing the perceptions of teachers about the problems facing them. Of the 44 problems identified and classified, the five most serious concerned dissemination of the new curricula.

8. Haggis, S.M. Science education in national development. *Science Teacher 39* (February 1972) p. 49–51.

   Discusses innovations by nationals for nationals, with specific reference to Nigeria, and its science teachers association. Outlines some ways in which Unesco can help in innovation.

9. Hurd, Paul DeHart. *New Directions in Teaching Secondary School Science.* Chicago: Rand McNally, 1969. 239p.

   Pages 186–202 contain outlines of some development processes of PSSC, and of Project Physics up to that date.

10. Kerr, J.F. Curriculum change in emergent countries. In: Howson, G. (ed.). *Developing a New Curriculum.* p. 57–78. London: Heinemann, 1970. 149p.

    Considers the national goals of emerging countries as a determinant of curriculum; and examines the influence of Ministries of Education and universities (and conflict between them) and of Curriculum Development Centres.

11. Landbeck, R. Diffusion in SCISP. *Education in Science* No. 56 (January 1974) p. 28–30.

    The author is Phase 3 co-ordinator of the Schools Council Integrated Science Project, and therefore concerned with diffusion. The methods are planned decentralisation and area meetings, and most of the area co-ordinators are Local Education Authority science advisers.

12. Leide, B.G. and Sloan, D.J. *SSP Physics Evaluation.* Nairobi; Kenya Institute of Education, 1973. 53p.

    Gives some information about School Science Project physics.

13. Lewis, J.L. (ed.). *Teaching School Physics.* Harmondsworth: Penguin/Unesco, 1972, 416p.

    Chapter 16 gives very useful advice on setting up a curriculum development project and planning for implementation. Appendix A has case-histories of a number of projects; Project Physics is outlined in Appendix B.

14. Mayatt, J. Curriculum development is teacher development. *Educational Development International, 2,* 1, (January 1974) p. 2–4.

    Makes a case for active teacher participation in a curriculum development project. Teachers centres are seen as invaluable aids to dissemination.

15. Newton, E.D. Educating teachers for the new science curriculum: a dilemma. *School Science and Mathematics 71* (1971) p. 17–23.

    A report of an investigation into science teacher education methods courses in USA, which revealed

that tutors believe in enquiry teaching but are failing to convince their student-teachers.

16. Nickelson, A.L. Nigeria moves ahead in science curriculum development. *Science Teacher 38* (April 1971) p. 40.

    Outlines moves to produce original Nigerian programmes, not adaptations.

17. Norris, S. A Canadian views British and American secondary school science. *Science Education 53* (1969) p. 35–42.

    Gives a limited comparison of the British and American projects and ends up lamenting that Canada fell victim to the hard sell of the United States. He feels that Canada should have invented its own courses, borrowing from the United Kingdom.

18. Novak, J.D. A case study of curriculum change – science since PSSC. *School Science and Mathematics 69* (1969) p. 374–384.

    Outlines the situation which led to PSSC and provides an insightful survey of science curriculum development in America in the 50s and 60s. He pays special attention to the influence of NSF and the scientist/educator dichotomy in curriculum leadership.

19. Page, R.L. Reformation or revolution in teacher training. *Education in Science* No. 42 (April 1971) p. 17–19.

    Suggests that teacher education in the United Kingdom is not as effective as it should be and that teacher-educators need re-education. He suggests a model for a unified approach and a system of co-operation with extra-college organisations.

20. Reay, J.F. (ed.). *Integrated Science and Teacher Education.* Trinidad: UWI/Unesco, 1974. 258p. job cards. Report of Unesco/CEDO workshop in the Caribbean.

21. Rogers, E.M. *Improving Physics Education through the Construction and Use of Various Types of Tests.* Paris: Unesco, 1972. 119p. The report of a regional seminar in Montevideo.

    Suggests that discussions on questions and problems can be a good starting point for arriving at a realistic philosophy of science education.

22. Rutherford, F.J. Preparing teachers for curriculum reform. *Science Education 55* (1971) p. 555–568.

    The author was one of the three co-directors of Project Physics and he puts a very high priority on teacher education, including changing the perceptions of the teacher educators. He proposes a comprehensive plan for disseminating the new curricula.

23. Teston, Bro. J.D. Innovations in Philippine science teaching. *Science Teacher 37* (October 1970) p. 32–33.

    Bro. Teston was an initiator of the Philippines project. He outlines the situation which made the project necessary and briefly describes some elements of the project.

24. Thomas, Kosonike. The training of scientists and technologists in developing countries. In: Gillon P. and Gillon, H. *Science and Education in Developing States,* p. 169–177. New York: Praeger, 1971. Report of Fifth Rehovot Conference in Israel.

    The author, who is an engineer of Fourah Bay College, Sierra Leone, says that a country must develop the tertiary education it needs for its own society and for national development.

25. Unesco. Modes of action. In: *La Enseñanza de Las Ciencas en America Latina,* p. 79–105. Montevideo, 1973. 113p. (Report of a regional seminar).

    Stresses the value of work groups in production and diffusion and makes proposals for the region. In Spanish.

26. Wastnedge, R. Whatever happened to Nuffield Junior Science? In: *Problems of Curriculum Innovation I,* p. 35–40. Walton Hall: the Open University Press, 1971. 128p.

    A small case study of the development of this curriculum.

27. Williams, I.W. *WISCIP: a Case Study in Curriculum Innovation.* Unpublished paper written at University College, Swansea, and submitted in draft to the Dean of Education, University of the West Indies, 1973. 71p. appendices.

    An absorbing account of the problems and challenges that faced a one-year project charged with the task of producing a three year integrated science curriculum, and the attempts made at solving these

problems and meeting these challenges.

28. *Project Physics Newsletter* (October 1974), 42 Consul Road, Brookvale, N.S.W. 2100, Australia.

29. Booth, N. The impact of science teaching projects on secondary education. *Education in Science* (June 1975) p. 27–30.

30. Lockhard, D. *International Clearinghouse Report* Maryland 1973.

31. *New Trends in Integrated Science Teaching Vol. 3* (Report of Maryland conference).

11 The interface between physics and mathematics

The interface between physics and mathematics is one which arouses considerable interest, it might almost be said considerable passions. Two papers were written as the basis for discussion at the Edinburgh conference. The first by W.U. Walton was concerned with school level, the second, by K. Maurin, with university level. At the conference itself the working group divided into two sub-groups reflecting this division, although such was the interest that joint meetings were usually held.

A distinguishing feature of this working group was that it was concerned with problems that cannot be solved by physicists alone, but which require active and close cooperation with mathematicians. In the event, the author of one of the trend papers and two other members of the group were mathematicians deeply involved in the teaching of mathematics at various levels and other members were teaching mathematics to science and engineering students even though they were not themselves professional mathematicians.

During the discussions a number of very critical comments were made concerning the teaching of mathematics both at school and university levels. Some of the existing difficulties between mathematicians and physicists would seem to arise from two main sources. First the relationship between the two disciplines is not a symmetric one. Physics cannot exist and develop without mathematics. Secondly 'new' mathematics has been introduced without any real consideration of its effect on the teaching of physics.

It was noted that the introduction of 'new' mathematics has taken place in many countries without consultations outside a limited circle of mathematicians, certainly not with the cooperation of physicists, not to mention society at large. This approach inevitably leads to isolation of school from society. It was noted in the discussion that the reform activity has now to some extent subsided and serious dialogue with physicists has now begun to take place. It is hoped that this chapter, based primarily on the trend papers with recommendations made by the working group, will further this dialogue. The ultimate solution must necessarily be worked out in each country.

11.1 INTRODUCTION

Physics teachers these days often complain that their students cannot estimate, cannot calculate with approximate numbers, cannot use ratios and proportions, cannot use decimals, cannot read graphs and do not know how and when to make approximations. As physics teachers it is doubtless part of our duty to teach them many of these skills, but all too frequently there is blank astonishment if we expect that students should have seen some of the techniques introduced, explained or practised in their mathematics classes.

The National Assessment of Educational Progress conducted in the USA during the late 1960's [13] revealed that only 25 per cent of the adults tested knew that doubling the dimensions of a cube would increase its volume 8 times. A teacher recently reported [57] on students who can solve $x = yz$ correctly for y, but cannot solve $F = ma$ for m. Many students have great difficulty in making a reasonable estimate of the area of an irregularly shaped oil film [7], and most physics teachers know that, even if given the area of the film and the volume of the drop that made it, students have trouble calculating the thickness of the oil film [68].

These problems impel one to explore more deeply the interface between the teaching of physics and mathematics. For this reason, the present chapter discusses (i) the origins of the lack of transferability across the interface, (ii) the developments and trends attempting to make this interface more permeable and (iii) what actions might be taken to see that students can benefit to the maximum extent from the complementary teaching of mathematics and physics.

11.2 THE POSSIBLE ROLE PLAYED BY THE NEW MATHEMATICS IN THE DIFFICULTIES WHICH STUDENTS HAVE WITH COMPUTATION IN PHYSICS

We will look first at the character of the 'new' mathematics, gradually introduced as a school subject since the middle 1950's, and then briefly review international attempts to assess the state of mathematics and science in the schools.

11.2.1 The Character of the New Mathematics

The 'new' mathematics may be characterized by its goals, its content and its instructional methods. These have not been the same everywhere, but we shall see that there is a fairly large area of common thought and practice.

The differences in emphasis in the goals and pedagogy of the 'new' mathematics in the United States and the United Kingdom are probably a result of the different groups which took the lead in developing the new curriculums. In the United States, university mathematicians took the lead [50, p25]. The goal was to reveal mathematics as an important intellectual structure and the practice of mathematics as a creative endeavour. Little emphasis in practice was put on its utility. Understanding the basis of algorithms would lead to their effective learning and use [69] and axiomatization of algebra would show the unifying power of mathematical structure.

In the United Kingdom, a group of schoolmasters led the way to curriculum reform. They inferred the content of school mathematics from the 'manner in which mathematics is practiced by professionals at all levels' [60, p16]. A major aim 'is to make school mathematics more exciting and enjoyable and to impart a knowledge of the nature of mathematics and its uses in the modern world'. The British believed that the structure of mathematics should be revealed gradually in a cyclically and inductive way and only fully formalized in a rigorous way at the university level.

It is always difficult not to overdo generalization and the characterizations above, which represent the larger projects in each country, should be tempered by the fact that, even within a single country, the differences in style of 'new' mathematics may be as great as the total difference between the School Mathematics Project (SMP) in the United Kingdom and the School Mathematics Study Group (SMSG) in the United States.

In spite of the different approach to goals and methods, there is general agreement on the content of the 'new' mathematics. Most of the mathematics taught is still the old and necessary mathematics, but with less emphasis on manipulation and drill and a 'reduction of the complication of the examples to which ideas are applied' [60, p17], [21]. The new content is typified by the language of sets, matrices, transformational geometry, vectors, symbolic logic and statistics. There are more concepts, more symbols and a more precise language than before.

What might one expect to be the effect of these changes on the teaching of science? No one can quarrel with the desire of mathematicians to present their subject as one with a structure and practice in its own right. As physicists, we want to show the structure of physics with its great unifying laws, but it must not be overdone. There are many students who seem to be able to value only that which is familiar or useful. Even though students may not be drilled to the extent that they once were, we should be pleased if the processes of mathematics are taught, for we can provide, as physicists, situations in which meaningful practice can take place. Of the new topics, no one would question the value to physics of vectors or elementary statistics. Matrices can be used in studying collisions on air tracks [49] multiple reflections in mirrors [12] and in solving simultaneous equations which might arise in electrical networks. Transformational geometry has many uses in optics [47].

We should be pleased that all of these new skills and insights are available, except for the gnawing suspicion that something must have slipped, since the students still cannot do so many elementary things. Are there psychological factors which account for many above-average students not learning to use ratio and proportion [37], [28] even though they have been 'taught' more than once? Can the ideas of linear and exponential functions be understood by a student who is not always sure of ratio and proportion? Are there more students who cannot transfer their mathematics to the physics class than there were before the 'new' mathematics? Let us turn to the work of the International Association for the Evaluation of Educational Achievement to see if it can throw light on the problem.

11.2.2 International Evaluation in Mathematics and Science

After several years of preparation, the International Association for the Evaluation of Educational Achievement (IEA) conducted in 1964 a cross-national evaluation of mathematics achievement in 12 countries [26]. One of the purposes was to determine the effects of various independent variables, present in different school systems, on achievement in mathematics. One independent variable chosen for study was the amount of 'new' mathematics taught in the various systems. This variable was to be assessed in more than one way, but because of difficulties in reducing the data, we have to rely solely on the response of teachers to the question, "Are you at present basing any of your teaching on the 'New Mathematics'?" [26, V1, p268]. One would expect that in countries where a high percentage of the teachers responded 'yes' to this question that the students would do better on the sub-test concerned with sets and logic than in countries where the percentage of teachers using 'new' mathematics was low. This was indeed the case. Among the 12 countries and for the students studying mathematics in the last pre-university class [26, V2, p33], the sub-tests with the highest correlation with *Percent 'New Mathematics'* were those on *Sets* (r = .38) and *Logic* (r = .47). How did the students in these same countries do on the other sub-tests? The correlation of *Percent 'New Mathematics'* with the sub-tests on *Computational, Algebra and Geometry* were −.34, −.39 and −.53 respectively. These correlations are not of particularly high absolute magnitude, but the difference in sign is dramatic. Perhaps 'New Mathematics' pushes something out of the curriculum after all, but one cannot infer a causal effect from a correlation study alone.

Six years later, the Achievement Study in Mathematics an Evaluation of Science Achievement took place in 1970 [6]. It would be tempting to compare 'new' mathematics with physics achievement on this latter evaluation, but as there may have been great changes in the curriculum in some countries over a six-year period, no meaningful comparisons could be made. It is disappointing that the 1970 study did not include mathematics as an independent variable in any significant way.

The difficulties of students in applying mathematics to physics may not be solely the result of the 'new' mathematics. These difficulties may have grown worse in recent years for a variety of reasons, with the 'new' mathematics being only one of several. Other possible reasons for the difficulties we perceive in the mathematical abilities of our students may include the fact (1) that we reach a broader spectrum of students, (2) that we are trying to teach more sophisticated courses, (3) that we have an overloaded curriculum in both subjects, (4) that social changes have caused students to be less motivated towards mathematics and physics, (5) that teachers with little training were asked to teach new mathematics in the primary schools.

One solution to the problem may be finding more time in the physics and mathematics classes in which to deal with the problems common to both. This requires a look at the attempts that have been made to coordinate as well as to improve the teaching of mathematics and physics.

11.3 TRENDS IN EXTENDING THE PHYSICS/MATHEMATICS INTERFACE

The physics/mathematics interface may be likened to a semi-permeable membrane. Small molecules may pass through from either side. What may be needed is a much larger area of contact between the subjects so that the rate of transfer may be greatly increased. In this section international efforts at enlarging this important interface will be discussed, followed by a description of local developments in a few countries.

11.3.1 International Efforts

At the Royaumont Conference of 1961, Dr Marshall Stone proposed coordination of mathematics and science teaching and that this coordination should be the theme of a conference in the near future [15, p21]. Professor Jean Dieudonne of France proposed that Euclid should go and in its place matrices, elementary calculus, curve sketching, properties of complex numbers and polar coordinates would be put into the curriculum [15, p35–38].

The Dubrovnik Conference of 1960 suggested syllabuses to cover modern topics. It recognised the importance of coordinating the teaching of science and the teaching of mathematics, but did little to implement this coordination [41, p6].

At the Athens Conference in 1963 [16] H.O. Pollak presented several examples of situations requiring applied problem formulation [43] and participants suggested that lists of such problems suitable for schools be supported by the Organization for Economic Cooperation and Development (OECD) [16, p236]. The danger that these problems might be compartmentalized into a separate applied-problems course was pointed out as one to be avoided. To overcome the danger of the list becoming a static set of ageing problems, it was suggested that a brochure should appear annually, giving actual new problems as well as up-to-date bibliographies.

In *Teaching Physics Today* (OECD, 1965) W. Knecht pointed out that the coordination of mathematics and physics is becoming more difficult. He said that the physics teacher is led to introduce certain key concepts earlier in order to present the material in as analytic manner as possible and the mathematics teacher tends to put off these same concepts as he is anxious to develop modern theories based on a thorough study of sets and structures [30, p28].

W. Servais in Unesco's *New Trends in Mathematics Teaching, Vol. I* [63] goes into detail on the problems of coordinating the teaching of mathematics and physics at secondary school. His article gives five themes with which the physics teacher can furnish the mathematician and three examples of schemes with which the mathematician can aid the physicist [53].

Finally the conference, called for in 1961, was held at Lausanne in 1967 as a symposium on *Reform and Coordination in the Teaching of Mathematics and Physics* [10]. Before the conference, a questionnaire was distributed concerning the articulation of mathematics and physics teaching. The questionnaire, answered by 65 professors, indicated that two-thirds insist that the two disciplines be coordinated. The questionnaire produced a list of physics topics useful to motivate mathematics. The respondents almost all favoured keeping trigonometry in the curriculum though with much less emphasis on identities. Substantial majorities were opposed to teaching groups and matrices in secondary school. A majority was also in favour of using a common notation and common definitions in both subjects and a great majority favoured introducing statistics and probability into the curriculum [10, p245–257].

Thirteen recommendations, closely related to the topics of the questionnaire, were made by the participants about the coordination of the teaching of mathematics and physics. Of special interest were the recommendations that "it is necessary to develop both the aptitude of pupils for identifying mathematical situations encountered in physics and their skill in the use of key mathematical tools, particularly algebraic calculation", and that the "model concept should play a major part in both mathematics and physics teaching". A final recommendation was that "coordination must be established permanently and the question periodically re-examined at international symposia" [10, p264].

At Utrecht in 1967 a colloquium was held on *How To Teach Mathematics So As To Be Useful*. In the opening address, Professor Hans Freudenthal pointed out the error of "teaching pure mathematics first and afterwards how to apply it . . . . people are able to apply simple arithmetic but not quadratic equations or even linear functions" [17].

Professor Murray Klamkin felt that there is "much too little emphasis on geometry and physics" in mathematics teaching and went on to discuss various aspects of problem solving, stressing the need for unsolved problems, problems in context and vertical versus horizontal problem solving [29].

In the 1970 *New Trends in Physics Teaching, Vol. II*, Professor H.R. Crane continues the theme set by the above papers, that if we teach our students "to solve only problems that are already formulated . . . . and ready for solution," then "they will be helpless to formulate even the simplest problems out of a situation or to question the world" [9, p371]. He gives 12 sample problems in five major categories where the student has to refine the problem statement, select appropriate data and consider the consequences of his answers. The problems require only elementary mathematics.

In *Teaching School Mathematics*, 1971, Professor E.A. Peel of Birmingham, U.K., describes psychological and educational research on growth of children's thinking and problem solving which support the need for situational and real world problems in mathematics [45]. W. Servais, in the chapter "The Training and Retraining of Mathematics Teachers", calls for the training of all mathematics teachers to include courses in one or two science subjects. "Only in this way will the teacher . . . . be capable . . . . presenting motivations and work regarding the application of mathematics" [54, p239]. He calls for the young mathematics teacher to be trained in the method of situations.

In his presidential address at the *Second International Conference on Mathematics Education* in Exeter, 1972, Sir James Lighthill called for the use of many concrete examples to show the wide-spread utility of mathematics. But at the same time he said one should teach the art of applying mathematics by investigating at least one field "at sufficient depth to give an impression of the subtle ways in which applied mathematics succeeds in making its contributions. The language used in that field must be at least partly put over and its terminology related to mathematical terminology" [35, p98]. He stressed the importance of keeping the real situation in mind, even during the process of mathematical solution, so that one may be aided at arriving at a *good* solution. This seems to be the practice of the *Further Mathematics* books of the School Mathematics Project where one book is devoted to vectors and mechanics and another to differential equations and electrical circuit theory [60, p191].

At the same conference Anthony J. Malpas reported on his efforts to determine the mathematical skills necessary for secondary school science (physics, chemistry and biology are each treated separately) and the extent to which courses in modern mathematics provide for the development of those skills. He found that there was a good deal of coordination between these subjects in the British programmes but "one is struck with how little use is made in the science courses of the many other ideas which go to make up a modern course like the School Mathematics Project" [37, p28]. He cites the need for materials which could be used by both the mathematics and physics teachers in making a joint approach to teaching topics in the overlap areas. Finally, he points out that, in spite of the fact that certain topics are treated in both courses, there are persistent reports from teachers on the difficulty students have with these topics. There may be important psychological components to these difficulties to which more attention should be given [15, p28].

An entire chapter in *Teaching School Physics*, a Unesco sourcebook published in 1972, is devoted to "Physics and Mathematics" [33, p151–160]. The case is presented against subordination of one subject to the other and it is urged that each subject must be true to its own structure, but the authors tend to favour more coordination and some convolution of the interface between the areas so that there is a greater crossflow of ideas and skills. Many mathematics teachers believe that mathematics starts from situations and physics is unusually rich in situations that are readily mathematized. The chapter ends with three examples which show that topics can be found that are interesting both mathematically and physically and that do not require inordinate demands on the students. Such problems should make collaboration mutually beneficial.

In the chapter 'Application of Mathematics' in *New Trends in Mathematics Teaching Vol. III,* the call for applications is made on the basis of three points. (1) *"For motivation.* Many pupils are not moved by curiosity about mathematics but they can be persuaded to learn mathematics as a tool for solving some other problem that appeals to them" (but of course it must be pointed out that for some the converse may be true). (2) "*For cultural reasons* . . . . Newtonian mechanics . . . . is an important intellectual system with great effects on our lives". (3) "*As a service subject*". So that one can avoid having mathematics taught ad hoc and badly in other subjects [64, p81]. The usefulness and extensions that computers can bring to the subject are indicated and the need for more suitable problems is again pointed out. Several applications of arithmetic, algebra, geometry and calculus are sketched. A long-term aim of mathematics, not noted heretofore, is that "pupils must learn the difficult skill of reading mathematics in books when they need it and that this education should be a foundation for such intelligent reading" [64, p89].

We are left with one unsettling observation: even though we may come up with "many good potential sources of applications (for classroom use) experience indicates that few good applications of mathematics are possible within the limits of the conventional timed examination" and students learn chiefly what they are examined on [64, p91].

11.3.2 Local Efforts at Extending the Physics/Mathematics Interface

(a) *United States efforts*

The Physical Science Study Committee (PSSC) text begun in 1956 was published in 1960 [46] and contained more mathematics than any previous American high school physics text. The authors felt that to present significant physics they could not be limited by constant accelerations and forces. To deal with varying rates they needed calculus and so they built it into chapter 5, "Motion along a Path", without scaring off the student by naming it calculus. Vectors had always been present, primarily to deal with static forces, but the PSSC authors went much further and considered the vector nature of motion in a plane. In general the authors dealt with the coordination of mathematics and physics in a natural way by teaching the necessary mathematics along with the physics.

In 1963, the School Mathematics Study Group (SMSG) began an experiment teaching *Mathematics Through Science* [52]. Three small books were produced to be used as supplementary material at the 12 to 14 year old levels. No science background was needed on the part of the student and exercises with real objects were performed in the class. Linear measurement, Hooke's Law, levers, bouncing balls and gas laws were among the topics studied. However there was little pretence that these topics were studied for their own sakes. It was usually clear that linear functions, inequalities and other mathematical topics were the real subjects under discussion. Evaluation of the project gave extremely mixed results and the project was dropped. However it was revived briefly in 1968 for an evaluation study that included attitudes. The mean achievement gains in this trial were all significant and positive, but most of the significant mean changes in attitude were negative. Further analysis showed however that there was a group of about 8 per cent who had consistent positive changes and another group of about 6 per cent who also made strong negative changes [23, p20]. In other words at age 13 there were quite divergent emotional reactions to using science exercises to motivate mathematics teaching.

The Harvard Project Physics Course begun in 1962 and published as *Project Physics* in 1970 [24], continued to include much of the mathematics that PSSC had introduced into the physics course and added the technique of making measurements on projected film loop images as a source of data for problems.

In 1967 the Cambridge Conference on School Mathematics called together a group of mathematicians, scientists and educators to consider the coordination of science and mathematics at the elementary school level [4]. The thoughtful report was rich in many ideas for problems and research projects that could be carried out at different depths by students at different school levels and included as well sections on denominate numbers, functions and graphing, modelling, spatial visualization, motion and symmetry and statistics. An outcome of this conference was the funding in 1970 of the Unified Science and Mathematics for Elementary Schools (USMES) programme [36]. This programme attempts to teach 'real problem' solving by utilizing situations where groups of children work together on a problem, such as how to improve a school crossing, and then make recommendations involving safety and costs. The quantitative and other skills needed in studying the problems are made available in a library of cards through which the mathematics is learned and practiced. This successful project might serve as a useful model for coordinating science and mathematics at higher levels.

Begun in 1965 and completed in 1971, the Engineering Concepts Curriculum Project [34] represents the boldest United States project integrating mathematics and physics. Flow diagrams, linear programming, calculus and modelling are used to attack problems in traffic engineering, shock absorbers, population dynamics and navigation. One serious question brought to light by this project is who can and who should teach such a course. Because it is clearly not just mathematics and not just physics the adoption of the project's text *Man Made World* has lagged behind what might be expected of a text of this quality.

Finally in 1972 the Computer and Laboratory Calculus (CALC) Project of Massachusetts Institute of Technology and later Education Development Center began to produce materials to teach calculus based primarily on physics experiments [47], [51]. Velocity recorders, accelerometers, water flow systems and dry cell life time tests are parts of the programme which attempts to motivate and model mathematical processes with physical systems. Graphical and numerical techniques are used to show students who may not be conceptually ready for a more abstract treatment the power and utility of calculus.

(b) *British efforts*

Most of the major British mathematics projects contain a greater emphasis on applications than do their American counterparts. However, British journals nevertheless indicate some dissatisfaction with the lack of coordination between subjects and lack of transferability of mathematical skills to the physics classroom [7], [47]. Consequently, in 1971, a Mathematics/Science Links Working Party was set up. At a conference in Oxford [59] this group suggested several areas for further study: computations, scale and dimensions, how and when to use approximations, the timing of topics, differences in notation and whether the logical sequence of mathematics topics should take precedence over the less fixed order of physics topics. C.A. Croft called for mathematics and physics teachers to cooperate and attributed the previous poor coordination to the teachers themselves, to the lack of emphasis given to integration in the Colleges of Education and to the Examination Boards which have not encouraged a common approach [53]. Through the invitation of this committee, several articles have been published in British journals on the efforts and examples which many teachers have used to forge links between science and mathematics teaching [21], [47], [67], [68].

Apparently an outgrowth of the above group, is the *Science Uses Mathematics* (SUM) project at Chelsea College, London University, which is developing modules of work that science and mathematics teachers can use to set joint work for their pupils. Two such modules are 'Symmetry and Crystal Structure' and 'Indices and Molecules' [8].

At the A-level stage several groups are working to provide independent study work in physics and mathematics. The *Sixth Form Mathematics Project* [31] has produced 'packages' on *Indices, Quadratic Models* and *Limits*. Several others are under development. A distinguishing feature of these materials is that "Each piece of mathematics included in the project material is in some way related to a situation. In doing the mathematics we investigate the *possibilities* that exist in these situations" [54, p51].

The *Mathematics in Education and Industry* project is developing material using conventional teaching methods on statistics, applied calculus, vectors, matrices and linear equations and numerical methods and approximations. Much emphasis is placed on computers and computing [22].

The *Continuing Mathematics Project* has developed a course on calculus using programmed learning texts and work on critical path analysis and flow charts, utilizing games [70].

Very useful work has been done by the Joint Royal Society/Institute of Physics' Physics Education Committee in compiling a list of the "Mathematical Needs of A-level Physics Students" [27]. The list is divided into minimum needs, very desirable abilities and the needs of students who will proceed to physical science or engineering at university. It was developed by physicists from their viewpoint, but was modified by consultation with mathematicians. The committee suggests that a complementary document be drawn up by mathematicians.

The English examining boards have established a new A-level subject, Physics-with-Mathematics, which includes calculus, vectors and statistics, has a much reduced physics syllabus and sets questions which involve the skills of both.

Finally, the *Nuffield Advanced Physics* team has produced an excellent book for teachers on supplementary mathematics which covers computation, functions and graphs, differentiation and integration, and exponential changes and probability [39].

We have already mentioned the SMP's *Further Mathematics* series which includes books on *Vectors and Mechanics* and *Differential Equations and Circuit Theory* [60, p191–192]. It appears that even if the ultimate coordination desired between mathematics and physics teachers has not been reached, a very good first approximation has been made and there is strong hope that the process will converge.

Some very positive moves toward the coordination of physics and mathematics are now taking place in the U.K. SMP has invited a group of physicists to work with it and develop an A-level physics course into which the mathematics is directly woven. A similar SMP group is at work at O-level. The Scottish Centre for Mathematics, Science and Technical Education is preparing a report 'Modern Mathematics and its Implications for Physics Teaching' that lists the mathematical needs of 'O' grade physics.

(c) *Other countries*

In Rome, Emma Castelnuovo has interfaced physics and geometry in her work for the first cycle in secondary schools. The work includes applications to probability and linear programming [5].

In China, geometry is studied in the physical setting of field surveying, using homemade instruments. Instruction is concrete and immediately relevant to social needs. Measurement, approximations, calculation and geometric constructions are emphasised [58].

In Sweden, the German Democratic Republic, the USSR and several other countries, the same teacher frequently teaches physics and mathematics, bringing about an element of coordination often missing in other countries where the teachers of these subjects are not aware of the topics and methods used by one another.

In the USSR there is great emphasis on computers, and special schools have been set up at secondary level to train computer programmers. There are also boarding schools specializing in physics and mathematics. The syllabuses of these schools are thorough and largely classical, with mathematical logic and the theory of sets being the last topics of the final year. These last topics serve as a climax to the curriculum, instead of being perhaps a stumbling block at the beginning, as they might in some curricula [66].

TRUAS-Physics (Radio and Television in Physics Education) in Sweden has tried to integrate mathematics and physics. Computers have been used and short TV programmes and texts have been constructed. The syllabus in school covers more material than formerly, leaving little time for practice work. The universities have initiated short review courses in mathematics at the start of the year to increase the proficiency of students taking technical subjects.

The German Democratic Republic, which for a time allowed mathematicians to graduate without studying physics, now requires studies in physics. Mathematics and physics teachers have always been required to study and to teach both subjects as already mentioned.

Several countries including India, Egypt and Malawi have introduced new mathematics on a limited scale within the last four years but are exercising caution about its expansion. Malawi has withdrawn new mathematics from its schools. Difficulties reported were that parents could not help their children, science teachers did not feel it was useful, the vocabulary was unworkable, students did not do as well in classical physics as before.

11.3.3 Summary of Trends

Modern Mathematics is being taught in more and more countries and will probably continue to be taught in most of them. The introduction of 'new Mathematics' and 'new Physics' took place in most countries without consultation between mathematicians and physicists. However, there is a trend in the 1970's for communication between curriculum groups in these fields and hopefully a move towards real cooperation.

The mathematical community has become more interested in the application of mathematics to various fields and with this interest there seems to be a growing interest in the teaching of mathematics so as to be applicable [29], [43].

11.4 PROBLEMS AND POSSIBLE ACTION

Most of the difficulties that arise from the trends described in the previous section can be classified into three areas: difficulties of instruction, difficulties over the curricula and difficulties related to the necessary materials. The first two are considered below with suggestions as to possible action in the future. Corrective action for the third category is to develop the material that is clearly needed.

11.4.1 Instructional Difficulties

(a) Students often lack *proficiency* in the mathematical skills that they know. For example:

Calculate T in the following: $T = 2\pi \sqrt{\frac{100\text{cm}}{980\text{cm/s}^2}}$

In this problem, students have difficulty handling the units, in taking the square root by any means (except a calculator), and expressing the answer to a reasonable number of significant figures.

(b) Students often cannot *transfer* skills from the mathematics class to their physics class. For example: a student can solve

$$2x^2 + 5x - 3 = 0$$

for x in his mathematics class but cannot solve

$$3 = 5t + 2t^2$$

for t in his physics class.

(c) Students are usually reluctant to make *approximations*. For example: in finding out the depth of a well in which the splash of a pebble is heard 3.1 seconds after it is dropped, the following equation arises at one stage of the solution.

$$\frac{d}{16} + \frac{6.2d}{1100} - \frac{d^2}{1\ 210\ 000} = 9.60 \text{ (d in feet)}$$

How many students would reason that unless d approaches a value of 1000, the term in d^2 is very small and can be ignored in view of the accuracy of the data? [2, p241].

(d) Students usually have difficulty with the *mathematization* of a situation; for example: "It has often been stated that to get his dinner a bat does not chase individual bugs, but merely flies during the hours of darkness with his mouth open. See if a rough calculation will prove this to be possible or ridiculous" [9, p378].

How does the student begin and where does the student get the crude data that he needs?

11.4.2 Actions for the Improvement of Instruction

(a) Work toward easing the above difficulties must be the *responsibility* of each individual teacher. Since the mathematics teacher cannot help his students to develop proficiency in techniques mainly of interest to physics, the physics teacher should be glad his students have had an introduction and know that he can provide practice of those skills in meaningful context. A reduction of content would allow more time to practice skills in both courses. For those students who go on to university, some lack of proficiency may be made up by short courses taken on entrance. These courses might well be of the Keller plan type.

(b) A mathematics teacher cannot be expected to teach explicitly for transfer of skills to a great number of fields. He can provide anchor points for bridges to other fields by using a variety of symbols other than x and y, but the physics teacher will have to be responsible for building conceptual bridges back to those few anchor points. Increased communication between mathematics and physics teachers is essential so that they become aware of their differing symbols, usages and techniques. Through this awareness they may simplify the student's problems with these differences.

(c) The teaching of how to approximate falls under a discussion of both content and method. L.J. Dixon has suggested, in connexion with the example cited above, that it is possible to organize a set of elementary theorems that will cover such examples and that mathematics teachers should develop such a topic for school-level algebra [11]. Physics and mathematics teachers can well work together on examples and techniques of approximations. Cooperation is essential as it is disastrous if one teacher plays down or contradicts the work of the other.

(d) The teaching of problem solving is much more than assigning a few 'word problems' for homework. Noah Lerman criticises typical physics problems and suggests and illustrates the use of interaction with a class in defining and solving open ended problems [32]. Teachers must explicitly teach how to apply mathematics and not let the skills of interpretation get lost between theoretical physics and pure mathematics.

(e) The availability of inexpensive electronic calculators may have a profound effect on each of the problems listed above, even if only one or two are available for an entire class. Their use may make up for some lack of computational proficiency, make more realistic and interesting problems possible, make more calculations possible leading to more accurate graphs and more ways of doing a given problem, make experimenting with numbers possible, make experimenting with alternative approximations possible, make numerical calculus possible.

However there may be some costs. Students may appreciate less the value of significant figures and the magnitude of numbers and have less practice in order of magnitude calculations. They may well not know when not to use a calculator for a simple calculation. For more on the potential of calculators see Pocket Calculators in School Physics by J.M. Osborne [42].

11.4.3 Problems Related to the Curriculum

(a) *Content and coordination*. The physics teacher often feels the need for mathematics that is either not taught by the mathematics teacher or not taught soon enough to be used in the physics class. The topic of integration is often needed to calculate work done before it is taught in mathematics classes. On the other hand, some topics in the new mathematics, such as matrices, may be more useful for advanced physics than for the physics under study at the time.

(b) *Conceptual difficulties.* The syllabus may require a topic that is conceptually very difficult at the particular age considered. Gubrud and Novak [19] showed that 16-year-olds were able to incorporate material on vector addition into a cognitive structure with clarity and stability but that 14-year-olds could not do so in the same learning period. Perhaps conceptual problems are at the heart of the often reported difficulties with the oil film experiment.

(c) *Teacher competency in a second field.* Teachers often do not have enough competency in the complementary field. It is difficult for a mathematics teacher to use physics for motivation and application if he feels unsure of himself with physical ideas and apparatus.

(d) *Evaluation.* Timed examinations seldom reward problem formation skills. The necessity of assessing a wide sample of a student's skills means that time for any one question is limited. Problem formulation takes a notably long time even for professionals; one often likes to 'sleep on a problem'.

11.4.4 Actions to Alleviate Curricular Problems

The alleviation of these curricular problems requires the cooperation of teachers, research workers, colleges of education, curriculum groups and examining boards at national levels. Work is in progress on each of these problems in several countries.

(a) On a small scale, N.G.G. Webb [67] has developed a scheme for coordinating the work of the mathematics teachers with other teachers in the same school. As noted previously, the mathematical requirements of physics have been specified by several groups in the United Kingdom [27], [59].

In each country similar groups must examine physics and mathematics courses, and work out both the prerequisites for each topic and the options that can follow each topic. The relationship of each topic to the other topics can profitably be shown in a partially ordered tree diagram similar to a PERT diagram. From such a diagram, possible sequences of mathematics and physics topics may be easily worked out.

Teachers from many countries have complained that there is too much content in the mathematics and physics courses. Serious consideration should be given to reducing the total content in order to go deeper into the topics selected and to inter-relate them.

(b) There is active research on cognitive problems in several countries, but ways should be found to make "research more relevant and the work of teachers more productive, by enlisting teachers as partners in the research enterprise" [64, p136].

More insight is needed into the following questions. 'What is the earliest age at which particular concepts such as vectors or proportion can be generally understood?'. 'What are the advantages and disadvantages of precise language and extensive use of symbols at different ages?'. 'What is the importance of geometry in formulating and interpreting problems?'.

(c) In those countries where mathematics and physics are taught by separate teachers, physics teachers must make the effort to become acquainted with the new mathematics. New teachers must be trained in the new mathematics as taught in the schools as well as in the mathematics necessary to study physics. SMP has developed a booklet *Modern Maths in the Science Session* for this purpose.

It will be extremely valuable if the majority of mathematics teachers have also studied physics. Physicists must make every effort to make physics attractive to mathematicians through choice of subject matter and method of teaching. This is important, even where physics is required for the study of mathematics.

A Physical Science Group has developed a four-year curriculum to train the physics and chemistry teachers. It includes a coordinated mathematics course [20].

(d) Alternative methods of evaluation must be developed to reward problem formation and solution-interpretation skills. We may be forced to give up the idea of evaluation based upon sampling a large number of skills in a short time, as is done in most examinations at present. Thus we will need to place more reliance on sampling by the teacher in unobtrusive but systematic ways and the development of a few important skills over a longer period of time [64, p123], [67].

11.4.5 Difficulties Related to Instructional Materials Needed

(a) *'Lead in' material.* There is a need for more material that is interesting and can motivate the development of mathematical techniques from situations that do not require extensive or extraneous background. An example is the bat problem quoted above.

(b) *'Links' and application material.* There is a need for more material that calls on a background in both physics and mathematics, linking the two through interaction and reinforcement. An example is described by R.H. Romer in a 'Matrix Description of Collisions on an Air Track' [49].

(c) *Situations ripe for problems.* There is need for more written or photographic material useful in giving students practice in formulating problems or mathematizing situations. H.O. Pollak's simple example, 'What is the best route to the airport' [44, p398] contains many issues to be resolved about both meaning and procedure.

(d) *'Hands-on' challenges.* There is a need, particularly in the mathematics class, for 'hands-on' or 'real world' situations that "constitute a challenge to the student's power of discernment or invention" [54, p242]. The following describes a simple piece of material for this purpose. A spirit-level is constructed from a 30 cm long plastic tube bent into an arc of 50 cm radius. The bubble responds in the direction of motion when the 'level' is given a shove. Why does the bubble move and to what is the displacement of the bubble related? See S. Garfunkel [18] for a description of this accelerometer and its use.

Work toward meeting the above needs for instructional material should be shared by associations of teachers, applied mathematicians and experts from different disciplines. Work is already in progress on such material in some countries. A conference on 'Comprehensive Problem Solving in Secondary Schools' was held in the U.S. in 1973 [14], [36]. An international publication that shared problem material and continually added new ideas for problem situations has already been called for [16, p236].

11.4.6 Summary and Actions Needed

The difficulties students have with applying mathematics to physics and the lack of interest many students have in mathematics that is not motivated by useful application, are well known. They have been known long enough that the responsibility for them cannot be placed solely on the introduction of 'new' mathematics. However, there is evidence that the 'new' mathematics may be a component of the problem. Individual teachers can do much in a personal way to promote greater transfer of skills across the physics/mathematics interface. There are many activities going on at national levels in research on cognitive problems and in the coordination of the curriculum, teacher education and examinations. Increased financial support must recognise this work as valuable.

Teaching the complementary arts of problem formation and solution interpretation remains, as it has perhaps always been, the major unsolved task of this interface. This challenge has been a subject at almost all of the international conferences mentioned in this chapter; and more than one resolution has been passed for the collection of material for this purpose. It remains for mathematics teachers, physics teachers, research workers and interested specialists to take on this task in a *personal* way and share our results through publications and conferences established for this purpose.

The following is a brief list of the main actions recommended above.

1. Increased communication and interaction between physics and mathematics teachers at the level to work on instructional problems.
2. The establishment of joint committees to coordinate the physics/mathematics curricula at regional and national levels.
3. All physics teachers should seek to understand the new mathematics, and to make use of it where possible in their physics lessons. .
4. Physicists should seek to make physics as attractive as possible to prospective mathematics teachers and mathematics teachers should be encouraged to use examples from physics in their lessons.
5. There should be a reduction of content in both mathematics and physics so that more time may be spent on realistic problem solving.
6. Ways to take advantage of inexpensive electronic calculators should be studied.
7. We must develop new instructional material and share it through publication.
8. We should promote research on the learning of mathematics and physics concepts.
9. We need to develop alternative modes of evaluation that do not handicap creative thought.

Finally it may be useful to hold seminars in developing countries on the physics/mathematics interface to prepare teachers and students for the impact of new goals, methods and content in the teaching of mathematics and physics.

11.5 REFERENCES

The references most useful as an introduction have been asterisked (*)

1. Beberman, Max. *An Emerging Program of Secondary School Mathematics.* Cambridge, Massachusetts, Harvard University Press. 1958.

2. Bowen, John J. Mathematics and the Teaching of Science, *The Mathematics Teacher,* Reston, Virginia, vol. 59, October 1966, p. 536–542.

3. Cambridge Conference on School Mathematics. *Goals for School Mathematics.* Houghton Mifflin Co., Boston, 1963. 102p.

4.* Cambridge Conference on School Mathematics. *Goals for the Correlation of Elementary Science and Mathematics.* Boston, Houghton Mifflin, 1969, 208p.

5. Castelnuovo, Emma. Differentes Representations Utilisant la notion de Barycentre (Different representations utilising the notion of the centre of gravity). *Education Studies on Mathematics,* Dordrecht vol. 2, 1969, p. 307–332.

6. Comber, L.D. and Keeves, J.P. *Science Education in Nineteen Countries* John Wiley & Sons, 1973. 403p.

7. Crofts, C.A. The Inter-relation between Mathematics and Science Teaching. *Education in Science*, vol. 43, June 1971, p. 20, 21.

8. Science Uses Mathematics. *Education in Science*, vol. 52, April 1973, p. 15.

9.* Crane, H.R. New Trends in Physics Problems. In: New Trends in Physics Teaching, vol. II, Paris, Unesco, 1972, p. 371–385.

10.* Dialectica. *Reform and Coordination in the Teaching of Mathematics and Physics. Dialectica* (Lausanne), vol. 21, 1967. 404p.

11. Dixon, L.J. Approximations and the Teaching of Mathematics and Science. *School Science and Mathematics*, vol. 70, December 1970, p. 829.

12. Eakin, D.M. An Application of Matrix Optics. *American Journal of Physics* (New York), vol. 34, no. 9, September 1966. p. 758–761.

13. Education Commission of the States. Science: National Results 1970. *National Assessment of Educational Progress.* Washington, USGPO, 1970.

14. Education Development Center. *Comprehensive Problem Solving in Secondary Schools: A Conference Report.* Boston, Houghton Mifflin Company, 1975.

15. Fehr, H.F. *New Thinking in School Mathematics.* Paris, OECD Publications, 1961, 246p.

16. *Mathematics Today, A Guide for Teachers.* Paris OECD Publications, 1964, 421p.

17. Freudenthal, Hans. Why Teach Mathematics so as to be Useful? *Educational Studies in Mathematics*, vol. I, 1968, p. 5.

18. Garfunkel, Solomon. A Laboratory and Computer Approach to Calculus. *American Mathematical Monthly* (Washington), vol. 79, no. 3, March 1972, p. 282–290.

19. Gubrud, Allan R., Novak, Joseph D. Learning Achievement and the Efficiency of Learning the Concept of Vector Addition at Three Different Grade Levels. *Science Education*, vol. 57, no. 2, 1973, p. 179–191.

20. Haber-Schaim, Uri. Preservice Education of Physics-Chemistry Teachers. *American Journal of Physics*, vol. 39, 1971, p. 721.

21. Harris, B.R. Do the New Maths and Science Schemes have much in common? *Education in Science*, vol. 47, April 1972, p. 17–20.

22. Hersee, John. Mathematics in Education and Industry: A-Level Syllabus. *Physics Education* (London), vol. vol. 2, 1972, p. 80.

23. Higgins, J.L. *The Mathematics Through Science Study: Attitude Changes in a Mathematics Laboratory.* Stanford, California, SMSG, 1969. 60p. (SMSG Reports No. 8).

24. Holton, G., Rutherford, F.J., Watson, F.G. *The Project Physics Text.* New York. Holt, Rinehart and Winston, 1970. 803p.

25.* Howson, A.G. *Developments in Mathematical Education.* Cambridge University Press, 1973.

26. Husen, T. (ed). *International Study of Achievement in Mathematics: A Comparison of Twelve Countries.* New York, Wiley, 1967. Vol. I, 303p, Vol. II, 365p.

27.* Joint Royal Society/Institute of Physics – Physics Educational Committee. The Mathematical Needs of A-level Physics Students. *Education in Science*, vol. 52, April 1973, p. 16–20.

28. Karplus, Robert; Peterson, Rita W. Intellectual Development Beyond Elementary School II: Ratio, A Survey. *School Science and Mathematics* (Kalamazoo), vol. 70, December 1970, p. 813–820.

29. Klamkin, Murray S. On the Teaching of Mathematics so as to be Useful. *Educational Studies in Mathematics*, vol. 1, 1966, p. 126–160.

30. Knecht, W. The Coordination of the Teaching of Physics and Mathematics. In: *Teaching Physics Today, Some Important Topics*, Paris, OECD Publications, 1965, 270p.

31. Knowles, Frank. An Approach to Applicable Mathematics. *Mathematics Teaching* (Lancashire), vol. 56, Autumn, 1971, p. 50–53.

32.* Lerman, Noah. Open-ended Problem Instruction in General Physics. *American Journal of Physics*, vol. 32, 1964, p. 927–936.

33.* Lewis, John L. *Teaching School Physics.* Harmondsworth, Penguin Books – Unesco. 1972. 416p.

34. Liao, T., Piel, E.J. Let's Get Relevant. *Physics Teacher,* vol. 8, no. 2, February 1970, p. 74–82.

35. Lighthill, Sir James. Presidential Address. In: *Developments in Mathematical Education,* Cambridge University Press, 1973.

36. Lomon, E.L., Beck, B., Arbetler, C.C. Real Problem Solving in USMES: Interdisciplinary Education and Much More. *School Science and Mathematics,* vol. 75, no. 1, January 1975, p. 53–54.

37. Malpas, Anthony J. Mathematics and Science in the Secondary School. *Education in Science,* vol. 52, 1973, p. 27–32.

38. National Council of Teachers of Mathematics. *The Teaching of Secondary School Mathematics.* Washington, NCTM, 1970 (33rd Yearbook).

39. Nuffield Advanced Science. *Physics Teachers Guide: Supplementary Mathematics.* Harmondsworth, Penguin Books, 1973, 121p.

40. Organisation for Economic Cooperation and Development. *Teaching Physics Today, Some Important Topics.* Paris, OECD Publications, 1965, 270p.

41. Organisation for European Economic Cooperation. *Synopses for Modern Secondary School Mathematics,* Paris, OEEC, 1962, 310p.

42. Osborne, J.M. Pocket Calculators in School Physics. *Physics Education,* vol. 9, p. 414, 1974.

43. Pollak, H.O. Applications of Modern Mathematics Suitable for Use in Teaching Secondary School Mathematics. In: *Mathematics Today, A Guide for Teachers.* Paris OECD Publications, 1964, p. 220–234.

44.* How Can We Teach Applications of Mathematics? *Educational Studies in Mathematics.* vol. 2, 1969, p. 393–404.

45. Peel, E.A. Psychological and Educational Research Bearing on Mathematics Teaching. In: *Teaching School Mathematics,* Harmondsworth, Penguin Books-Unesco, 1971, p. 151–177.

46. Physical Science Study Committee. *Physics.* Boston, Heath and Co., 1960. 656p.

47. Quadling, D.A. Mathematical/Science Links Committee: New Developments in School Geometry. *Education in Science,* vol. 44, 1971, p. 20–25.

48. Rogers, Eric M. *Improving Physics Education Through the Construction and Discussion of Various Types of Tests.* Unesco, Paris, 1972. 119p. (Workshop – Seminar Report).

49. Romer, R.H. Matrix Description of Collisions on an Air Track. *American Journal of Physics.* vol. 35, no. 9, 1967, p. 862–868.

50. Rosskopf, Myron F. Mathematics Education: Historical Perspective. In: *The Teaching of Secondary School Mathematics,* Washington, NCTM, 1970, 1970, p. 25.

51. Schey, H.M., Schwartz, J.L., Walton, W.U., Zacharias, J.R. A Laboratory Computer and Calculus Based Course in Mathematics. *International Journal of Mathematical Education in Science and Technology,* (Chichester), vol. 1, 1970, p. 115–130.

52. School Mathematics Study Group. *Mathematics Through Science.* Stanford, SMSG, 1964. Three parts, 399p.

53. Servais, W. La Coordination des Enseignements de la Mathematique et de la Physique au Niveau Secondaire. (The Coordination of the teaching of Mathematics and Physics at Secondary Schools). In: *New Trends in Mathematics Teaching, Vol. I.* Paris, Unesco, 1967, p. 184–201.

54. The Training and Retraining of Mathematics Teachers. In: *Teaching School Mathematics.* Harmondsworth, Penguin Books-Unesco, 1971. p. 235–252.

55.* Servais, W., Varga, T. (eds). *Teaching School Mathematics.* Harmondsworth, Penguin Books-Unesco, 1971, 308p.

56.* Seyfert, W.C. (ed). *The Continuing Revolution in Mathematics.* Washington, NCTM, 1968, 166p.

57. Swartz, Clifford E. The Great American New Math Swindle. Editorial in *The Physics Leader.* March 1973, p. 134.

58. Swetz. Frank. Field Survey: An Aid to Geometry Instruction the People's Republic of China. *School Science and Mathematics,* vol. 73, no. 4, April 1973.

59. Tammadge, A.R. Moves Toward Mathematics and Science Links, A Report of Work in Progress in Oxford. *Education in Science,* vol. 44, 1971, p. 17–19.

60.* Thwaites, Bryan. *The First Ten Years.* (School Mathematics Project), Cambridge University Press, 1972. 266p.

61. Unesco. *Educacion Matematica en las Americas–III.* Montevideo, Unesco, 1973. 268p.

62. *Las Aplicaciones en la Ensenanza y el Aprendizaje de la Matematica en la Escuela Secundaria.* Montevideo, Unesco, 1974. 166p.

63. *New Trends in Mathematics Teaching – Vol. I.* Paris, Unesco, 1967, 438p.

64.* *New Trends in Mathematics Teaching – Vol. III,* Paris, Unesco, 1973, 145p.

65.* *New Trends in Physics Teaching – Vol. II.* Paris, Unesco, 1972. 517p.

66. Vogeli, Bruce Ranion. *Soviet Secondary Schools for the Mathematically Talented.* NCTM, Washington, 1968.

67.* Webb, N.G.G. Developing a good Relationship between Mathematics and Science. *School Science Review,* vol. 54, no. 188, 1973, p. 441–449.

68. Williams, John. 'Why can't they divide?' or 'The Maths/Science Dilemma'. *Education in Science,* vol. 50, November 1972, p. 21–23.

69. Willoughby, Stephen S. What is the New Mathematics? In: *The Continuing Revolution in Mathematics,* Washington, NCTM, 1968. p. 4–15.

70. Winter, K.L. The Continuing Mathematics Project. *Education in Science,* vol. 59, September 1974, p. 31–33.

12

Assessment of student achievement in physics at secondary school and university levels

The assessment of student achievement in physics necessarily implies the identification of a number of desirable qualities or 'objectives'. If assessment takes place during, or at the end of, a course, it is reasonable to relate the qualities assessed to the objectives of the course. Normally a form of assessment is required suitable for ranking students and preferably suitable for assigning numerical or letter grades.

In this chapter, based on a paper originally prepared by C.B. Oguntonade, the development and trends in the assessment of students in various parts of the world are briefly reviewed. The problems and challenges currently encountered are then considered and some suggestions are made for the alleviation or investigation of problems and the possible response to challenges.

12.1 DEVELOPMENT AND TRENDS

Purposes of assessment

Two main aims are evident in assessing students:

(a) to select students for entry to other educational institutions or for employment,

(b) to provide feedback for both staff and students to assist them in planning further studies.

With regard to (a) it is common practice to use the same final assessment for the selection of students for both further education and for employment, and to express the results as a single parameter classification, or even simply as pass or fail. Information on achievement in the individual subjects or topics of a course is sometimes provided, but other achievement such as ability to remember, to solve problems, to do experimental work, and to describe and explain in written or spoken words, is rarely separately identified and assessed.

With regard to (b) there is an increasing tendency, particularly at university, for continuous assessment to be used not only for feedback but also for the accumulation of credits for annual and final grading.

12.2 OBJECTIVES

There is a definite trend toward increasing awareness of the place of objectives in teaching and assessment.

Educational objectives may be classified under four major headings:

I Cognitive (e.g. knowledge and intellectual skills)

II Affective (e.g. attitudes, feelings)

III Psycho-motor (e.g. manipulative skills)

IV Social (e.g. mutual cooperation, confidence, leadership)

Houston [1], Klopfer [2] and others, have developed lists covering a wide diversity of possible objectives. The aims of physics teaching in many countries are consistent with many of the objectives on these lists, although the corresponding courses have not necessarily been designed with those aims explicitly selected.

Two current sources for educational objectives can be identified for physics programmes: (i) statements of general educational aims directed, for example, towards students' formation and understanding of concepts, acquisition of inquiry skills and formation of attitudes and (ii) statements of national goals and philosophies which may possibly influence physics teaching aims.

National statements which can affect educational objectives may range from a call to produce more technologists, for example, to such specific aims as those in the USSR where there is emphasis, at all levels, on the 'polytechnic character' [3] of physics and its application in 'the development of materialistic outlook .... patriotism, internationalism and respect for labour' [4]. Recent physics curriculum development by various learned bodies [5] in Nigeria also aim at the national level; the government warns of the 'inadequate exposure of secondary school products to .... science and mathematics which are basic to enrolment for higher technological and scientific studies' [6].

Within the content of educational objectives, there is a general tendency to include alongside specialized physics programmes, courses in physics for a more liberal education. For example, the first degree physics course in the U.S.A. provides both for (i) preparation for higher degrees and (ii) liberal education as a preparation for life and careers [7]. In France, liberal education in physics is both a goal in itself [8] and a substratum on which higher education is built. The purpose of physics teaching in French universities is purely educational except in the *grandes ecoles* and *instituts* where the aim, being national, is to produce technical personnel.

12.3 ASSESSMENT SYSTEMS

Two distinct trends can be identified with regard to assessment systems. First, there is a tendency to move from central administrative procedures toward more localized systems. Secondly, there is a trend toward diversification of assessment techniques.

Administrative procedures in assessment involve selection of examiners, setting of questions, actual administration of the questions to students, marking of the scripts and publication (or release) of results. In the United States of America, the responsibility for these procedures lies mainly on the schools, colleges and universities. They grade the answers and keep a record of such grades. Multiple-choice questions are predominantly used. The Scholastic Aptitude Tests (SAT) and the Achievement Tests of the College Entrance Examinations Board (CEEB) are two standardized tests popularly used for selection into colleges. The Advanced Placement Examinations qualify successful candidates to start college physics courses at some advanced level. In the United Kingdom, the three modes of the Certificate of Secondary Education (CSE) have enabled schools within the last decade or so, to have more control of assessment procedures. Many other countries, however, still operate a nationally or centrally controlled system at school level. Examples are, France, the Federal Republic of Germany and some West African countries (under the West African Examinations Council – WAEC). In most countries university examinations are wholly controlled in the institutions concerned, but some of them employ external moderators, as for example in the United Kingdom.

There is an increasing use of continuous assessment, particularly in universities.

In relation to this a distinction can be made between

(a) diagnostic testing, which is for feedback purposes only and for which no student credit can be obtained.

(b) continuous credit, which has both feedback and credit aspects.

(c) end-of-course assessment, which is primarily for credit (or selection) purposes only.

In many universities a combination of continuous credit and end-of-course assessment is used. Many favour the continuous component accounting for between 20 per cent and 40 per cent of the final total credit.

With regard to (a) and (b) above, there are several aspects of during-the-course assessment techniques. These include:

(i) Assignments. These may be problem exercises or essays to be done in the student's own time.

(ii) Tests. Tests may include multiple choice, short questions, longer structured questions, and other longer questions often involving numerical problems.

(iii) Practical work. A variety of intellectual skills associated with experimental work can be assessed from answers to written reports. However, practical assessment may include a measure of manipulative skills assessed by direct observation of the student or by oral questions.

(iv) Projects. Project work for both individuals and groups, is increasing at all levels of school and university education.

(v) Short talks by students. These provide opportunities for assessing the ability to write and present talks, and also, if required, the ability to select and study a topic outside the main syllabus.

(vi) Oral examinations. Oral examinations are frequently used in association with essays or project work. Moreover, in some countries it is still the sole method of student assessment (e.g. USSR, Belgium, Italy).

(vii) Self assessment and peer assessment. In terms of diagnostic testing, self evaluation is important particularly in programmed learning. Assessment of a talk or a piece of work by peers can also be important for feedback purposes (and possibly assist staff in assessing credit).

(viii) Tutor impression. A tutor's subjective impression of a student with respect to particular objectives can be used to identify problem areas (feedback). However, subjective assessment is sometimes used to influence course credit, particularly for borderline cases.

End-of-course assessment, (c), normally consists of written papers. These can be classified into three types

(A) papers unseen by the candidate prior to sitting and which are closed book examinations,

(B) unseen papers but examinations to which students may bring limited, or unlimited written material, in book form or as student notes,

(C) papers for which students are given prior knowledge of the examination questions.

Questions normally found in end-of-course examinations are of the four types mentioned previously, see (ii) above.

12.4 COMPETENCIES USUALLY TESTED

There is a definite trend toward the specifying of course objectives and the designing of examination papers to assess these objectives. However, in spite of this, there are still many courses which have no explicit course objectives or where there is little relationship between course objectives and the competencies being tested. To analyse examination papers in these cases various methods can be used. One method is by use of request-verbs specified in questions and this method reveals that examiners in practice concentrate on testing cognitive competencies, for example, by grouping request-verbs according to the system suggested by John and John [9]. Table 1 shows the percentage attention paid to each of the six cognitive areas in the long questions at West African School Certificate (WASC) examinations from 1967 to 1974, and in the specimen questions for the proposed new syllabus. The table shows that attention has been concentrated on comprehension and analysis levels although there is always some focus on knowledge. The last three columns show that application, synthesis and evaluation which have been predominantly neglected are beginning to receive slight attention.

Table 1. Percentage Distribution of Request-Verbs into Cognitive Levels in Paper 3 of GCE and WASC Examinations

	1967	1968	1969	1970	1971	1972	1973	1974	S.Q.
Knowledge	4.0	8.6	8.3	13.3	9.5	13.3	13.2	7.9	8.5
Comprehension	48.0	47.7	33.3	36.7	38.1	40.0	38.8	34.2	47.1
Application	0.0	0.0	0.0	6.7	0.0	0.0	2.6	5.3	1.4
Analysis	40.0	42.9	45.8	40.0	47.6	46.7	38.8	28.9	38.6
Synthesis	0.0	0.0	12.5	3.3	4.8	0.0	3.3	18.4	3.0
Evaluation	8.0	0.0	0.0	0.0	0.0	0.0	3.3	5.3	1.4

S.Q. = Specimen long questions based on proposed syllabus.

For the same period, multiple-choice questions have been distributed approximately as follows: knowledge level, 26 per cent, comprehension, 34 per cent, application, 26 per cent, analysis and synthesis, 10 per cent, evaluation, 4 per cent.

Request-verbs used in university examinations are more sophisticated, but still concentrate on cognitive competences. They include: derive, integrate, calculate, solve, write an expression for, set up . . . . equation, write an essay on . . . ., interpret, discuss, compare, describe the procedure for . . . . There is hardly any question which does not require a fairly high level of skill in mathematics.

12.5 RESEARCH AND ANALYSIS

Empirical research efforts on physics assessment techniques are scanty, but some outcomes of such efforts are noteworthy. With regard to reliability and validity of examinations Chapman [10] has discussed the validity of tests and the importance of an item bank, while Lemaitre and Verhaegen [11] have considered the consistency in scores assigned by different readers on the same set of essay type papers in physics. McDaniels [12] experimented with a discreet grading system for Ph.D. qualifying tests and concluded that the 'real advantage of the discreet system comes from increased selectivity about the marginal students' and that the system 'works best when an examination consists of a large number of problems with uniform spread of difficulty'.

A number of research studies have been concerned with some aspect of the relationship between objectives, teaching and assessment. Bryant and Anderson [13] discovered that students' prior knowledge of performance objectives, significantly improved their achievement. Bridgham's study [14] concluded that a knowledge of the relative ease of grading improves involvement in physics courses. Rogers [15] has documented a comprehensive analysis of practical approaches to the construction of good physics questions. He emphasizes the importance of testing depth of understanding and application of physical concepts.

Research continues on the impact of self paced learning on assessment techniques. The majority of self-paced courses require evidence of 'mastery' to progress though self-paced units and the structure of self-paced instruction includes a variety of teaching methods which tend to increase the range of types of assessment. Barnhill III [16] found that some of the advantages of self-paced physics evaluation aimed at learning for mastery was the removal of 'pressure and uncertainties' of examinations and greater reliability of grading, while in another study [17] he points out that peer tutors can be used in grading.

Associated with the trend toward assessment of specific objectives and diagnostic testing is the trend towards criterion-referenced tests rather than normative referenced tests. Criterion-referenced tests are constructed to obtain measurements which are directly interpretable in terms of satisfying or failing to satisfy, a given criterion based on a level of achievement. Normative referenced tests aim to spread out the candidates in order to pass a given fraction.

The philosophies of recent physics curricula imply corresponding changes in teaching approaches and therefore in the methods of assessment and content of physics tests. The inertia between trends in curriculum change and assessment methods (which lag behind) is due to a number of practical problems, some of which are outlined below.

12.6 UNCERTAINTY ABOUT OBJECTIVES

To assess what a student has achieved requires an understanding of, and certainty about, what a student is *expected* to achieve. This is not easy or even possible if objectives of teaching a physics course are either non-existent or not clearly stated, as is the case with most physics courses today. Admittedly, there is a constraint to state curriculum objectives in implicit global terms while it is expected that the teacher who handles the course will translate such implicit objectives into specific ones for different parts of the programme. This expectation assumes the existence of short term measurable objectives which are correlates of the long term implicit ones. Thus one would expect a global objective such as 'to explain what physics is about and nourish an understanding of the principles and concepts of physics' [18] to be specifically transformed into explicit ones such as 'to state four (or five) distinguishing factors between the goals of physics and those of chemistry (or say geography)', 'to apply Newton's laws of motion in the explanation of stated phenomena', 'to use given data to predict events on the basis of known principles', etc. Two problems immediately arise from this expectation. The first is that as one moves from school level to university level, it becomes increasingly difficult to give thought to such specific objectives, probably because topics become much more complex and sophisticated, but more importantly because teachers (lecturers, professors) at that level hardly regard such exercises as sufficiently prestigious to deserve any attention at their level of sophistication. The second problem is that many teachers, at all levels, either do not bother to know the objectives of the courses they teach or do not have the necessary expertise to write explicit objectives.

Objectives about which one generation of educators and students were quite happy may become completely uncertain and irrelevant to the needs of another generation of students who will therefore find it unfair to be assessed on such objectives. The last two decades in the U.S.A. have witnessed physics programmes geared to enhance national prestige in the space race. Today, students in many countries are looking for objectives that have relevance to the realities of their future. Developing countries face greater problems and challenges in this respect because so few physics examination questions have direct bearing on laudable national development plans.

12.7 NON CORRELATION OF THE TESTS WITH OBJECTIVES

Where there are adequately detailed objectives, few problems arise in the correlation of tests with those objectives. On the other hand the existence of central, national and local examination authorities in various countries makes it difficult to have questions which match the specific objectives and teaching adopted in individual schools. Marking of the answers by external examiners aggravates the problem and generates other serious ones. For example, trained teachers may be prevented from applying their expertise because they are constrained to tailor their teaching towards examinations which are not of their own making; students look at their examinations as an 'artificial, cruel, formality imposed on pupils and teachers alike' [19]. (There is nevertheless in this situation a special rapport between staff and students, which some staff value.)

Another consequence is that curriculum change which should be enhanced by the extent of achievement of objectives is inhibited. The fact that all school and university physics examinations concentrate on cognitive competences belies such ideal objectives as 'to stimulate an interest in physics as an attractive and satisfying intellectual discipline' [20] or our emphasis, in methods courses, on scientific attitudes. A system by which practical performances are only judged in students' scripts hardly tests the ability to 'do physics in a laboratory . . . .' [21] nor does it assess achievement at the psycho-motor and affective domains. Even at the cognitive level, attention can be lopsided as shown in Table 1. A developing country which emphasizes technological know-how as an objective faces the challenge to explain why its students are rarely assessed at the 'application' level in physics. Although one would judge most undergraduate physics questions as sufficiently intellectually demanding, yet most papers hardly test sufficient skills and material to satisfy the diverse objectives which are gradually gaining attention in many universities.

12.8 TYPE AND QUALITY OF QUESTIONS

The relative merits and demerits of essay-type and multiple-choice questions in physics have been discussed by Houston [22]. Multiple choice questions in physics are still not popular for undergraduate examinations, in spite of much research and considerable experience in the composition and use both in schools and universities.

Some countries, for example France and the Federal Republic of Germany, are particularly averse to the use of this innovation, although, ironically, educators and psychologists in the latter country contributed significantly to the development of intelligence tests from which multiple-choice questions grew.

The design and evaluation of short questions and longer structured questions have received relatively little attention.

Oral assessments sometimes evoke strong reactions both for and against. On analysis it is usually found that the preparation of structured oral questions appears to be inadequate. Few educationalists would defend the use of oral exams as the sole or principal assessment procedure, although this practice persists in some countries.

12.9 USE OF TEST RESULTS

The feedback of assessment is often neglected yet in terms of attainment of objectives and curriculum evaluation the challenge of regular feedback must be accepted so that the teacher may know what he is doing right and where to improve, while the student concentrates on learning. Letter grades by themselves are not a sufficient aid to learning. What are our students doing wrong? What are they learning that is not tested? What are they asked, but not taught? What are the difficulty levels and discriminating indices of our questions? These are some of the relevant areas of feedback being neglected.

The accumulation of credit during the course raises the problem of how to assign a final mark. The problem is particularly apparent when the record of marks over a period shows a distinct trend upward or downward. Examiners tend to give a heavier weighting to performances near the end of the course.

12.10 COMPARABILITY OF SUBJECT MATTER AND ACHIEVEMENT

Examination results should indicate the achievement of a student on a specific programme. Comparability therefore involves a comparison of both the subject matter of the programmes and what is judged adequate for success or mastery.

The different examining and scoring systems in different countries make it difficult to establish an objective comparison of performance standards. This problem militates against free exchange or transfer of students from one institution to another in different countries or even in the same country (e.g. in U.S.A.). Internally, this is a price paid for freedom of choice of examining procedures, but, externally, the problem is that of interpretation of objectives, teaching methods and grading systems across nations. Science educators are in a precarious position in this respect because the problem becomes greater as we move towards the goal of greater flexibility in learning and examining processes; and at the same time we face the challenge of applying the relative accuracy of measurements in the sciences to the cross-comparison of grades in physics examinations.

12.11 RESEARCH

Kruglak's resource letter published in 1965, 1969 and 1970 [23] emphasizes the fact that 'the number of studies dealing with physics tests is quite small'. The situation has not improved significantly since 1970 as shown by the review in the first part of this chapter.

In particular, there seems to be very little research into the problems of assessing practical work, project work and performance in non-cognitive domains in schools and universities. Another problem is the assessment of experience in industrial and extra mural periods of study. The possibility of measuring student profiles over a wide range of abilities as well as across subjects, is indeed a challenge. It is already being tackled at the school level.

The nature of physics challenges physics educators to engage in research (not just of a purely statistical nature) which will help to improve assessment methods.

The nature and extent of the problems outlined above vary widely across nations and institutions. Therefore, there can be no panacea which will serve as a *sine qua non* for all time and in all places. The suggestions which follow are consequently quite generalized and will have to be modified to suit particular cases.

12.12 IMPORTANCE OF OBJECTIVES AND DIVERSITY OF ASSESSMENT

There is a need to stress the *importance of objectives* not only in designing a course but also in making a valid assessment of student achievement. Assessment should *cover as many objectives as possible* in that limiting assessment to only some objectives often limits the number of objectives considered important by teachers and students. The objectives, and the relationship between these *objectives and the methods of assessments, need to be clearly understood by students.*

Some objectives may be more effectively assessed by particular methods of assessment, however in general *a diversity of assessment procedures* in the assessment of any objective is likely to increase both reliability and validity. Characterized types of assessment such as multiple choice and orals, should not be deliberately excluded without good cause. In equipping a school leaver, or graduate, for employment in society, *the importance of the ability to communicate* by the written and spoken word should not be neglected.

12.13 ASSESSMENT OF EXPERIMENTAL WORK

Experimental work can be considered under three headings:

(i) the design of the experiment

(ii) the experiment itself

(iii) the analysis of the results

The first and the last can be assessed by written tests or oral methods, however the actual manipulation of apparatus must be assessed on the basis of *direct observation by the assessor.* Qualities to be looked for include actual dexterity in the manipulation of apparatus, initiative in treating unexpected equipment problems, resourcefulness and improvization, judicious choice and manipulation of variables, correctness of data recording from equipment, minimization of sources of error and maximized use of available facilities, oral answers to questions arising from performance, etc.

Projects should be assessed under several headings, including (i) progress during the project, (ii) the written report, and usually (iii) an oral defence.

While reliability of project assessment is a problem, the major contribution to unreliability is the variation in the projects themselves (e.g. compare a simple project brought to completion, with a difficult project in which, despite considerable effort, little progress is made). Sympathetic consideration must be given, in assessing projects, to the situation in which the student has been placed.

12.14 QUALITY OF QUESTIONS

There is clearly a *need for collation of the existing validated multiple choice questions*, at both school and university levels. A large enough item bank removes the need for security and allows widespread dissemination to staff and students. The opportunity would then be provided for an increase in their use, especially in universities. A fourth possibility would be to *consider a corresponding bank of short problem type questions.*

More attention should be given to the degree of reliability of oral tests and the relevance of their correlation, or lack of correlation, to other methods should also be given more attention.

The relative value of *structured longer questions* needs to be investigated and the *role of numerical problems should be more closely considered.*

12.15 STUDENTS' UNDERSTANDING OF ASSESSMENT PROCEDURES

The increasing use of a variety of assessment procedures and the use of continuous credit along with final examinations makes it imperative to *convey to the student the relative weighting* to be given to the several aspects of the overall assessment. When new features are introduced for credit assessment, students should be given a prior opportunity to experience them, but solely on a feedback basis. An uneasy situation can arise when 'during course assessment' is used for both feedback and credit purposes. The intentions of such simultaneous uses should be carefully considered.

12.16 COMPARABILITY OR DECENTRALIZATION?

The need for comparability of achievement is often expressed at exit and entry points at several levels of the educational system. In principle, only entry examinations would appear to be important but factors of scale require the need for exit examinations organized on a cultural basis. Such centralization puts a constraint on teachers in their desire to select detailed objectives and make corresponding assessments. One possible solution is to have *part of the examination local and the other part central.* It is possible that a similar division could be tried in an attempt to achieve comparability between larger groups, including different nations.

12.17 PROFESSIONAL TRAINING

In order for the considerable improvements in student assessment to be appreciated, it is essential that these aspects be clearly presented in the professional training of physics teachers. The danger of allowing professional training of teachers to lag behind curriculum development efforts in Nigeria has been pointed out [24]. It is therefore necessary that techniques of testing should be emphasized in pre-service professional courses while similar in-service courses should be a regular educational endeavour. There is empirical evidence that science teachers in Nigeria would respond favourably to regular in-service courses [25].

12.18 SUGGESTIONS FOR RESEARCH

The obvious response to the criticism of inadequate empirical research is more empirical research. The difficulty does not seem to lie in the identification of research problems in the field of testing in physics but perhaps it is in the fact that interest in this direction is stifled by the age-old monopoly of examining rights by some boards and councils. The fact that research into physics assessment techniques is most predominant in the U.S.A. where the assessment system is also most flexible seems to justify this assertion. Other difficulties may involve availability of funds, preoccupation with research in physics and an assumption that good tests can always be made up in a few hours by experienced hands. Test development centres ought to function in each country to encourage research into assessment techniques. The Educational Testing Service (ETS) in the United States is a good example. The Test Development and Research Office (TEDRO) in Nigeria plans to expand and function on a basis similar to that of the ETS.

Aspects of assessment which require further study and research include:

(i) the construction and use of criterion referenced tests (see 12.5)
(ii) the use of oral examinations in physics (see 12.8)
(iii) the interaction of all types of assessment with learning process (see 12.9)
(iv) the assessment of practical project work (see 12.11)
(v) the measurement of performance in non-cognitive domains (see 12.11)
(vi) the flexibility and desirability of profile assessment (see 12.11).

12.19. ANNOTATED BIBLIOGRAPHY

The books in the list below provide useful basic reading material for anyone engaged in assessing student achievement in physics at any level. It is not claimed that the list is comprehensive but the books give a good guide to other materials. .

Brown, S.C., N. Clarke, and J. Tiomno (eds). *Why Teach Physics?* Cambridge, Mass., M.I.T. Press, 1964. xxv 97p.

This is a report of the discussions at the International Conference on Physics in General Education, held in Rio de Janeiro, Brazil, in 1963. Sections 1 to 5 provide invaluable general background information necessary for a meaningful understanding of the problems of assessment in physics. Topics discussed include physics teaching in a developing country, science as a part of culture, the contributions of physics to liberal education, the design of physics courses and the role of experiments in the teaching of physics.

Comber, L.C. and J.P. Keeves. *Science Education in Nineteen Countries.* New York: John Wiley and Sons, 1973, 403p. bibliogr.

This is a unique and scholarly report of empirical research studies of different aspects of science teaching in nineteen countries all over the world. Chapter 6 deals with science curriculum and student performance while chapter 7 treats factors associated with differences in these countries in achievement in science.

Duchastel, P.C. and Merrill, P.F. "The Effects of Behavioural Objectives on Learning: A Review of Empirical Studies". *Review of Educational Research.* (Washington, AERA), vol. 43, no. 1, winter 1973. p. 53–69.

The role of behavioural objectives in education and their effect on learning are the focus of this review. Four categories of studies are examined: those dealing with (i) effect of objectives on learning, (ii) specific types of learning taking place, (iii) objectives and learner characteristics and (iv) the effect of the knowledge of objectives on the time taken to learn instructional materials. A comprehensive bibliography is included.

Houston, J.G. *Objective Testing in Physics.* London: Heinemann Educational Books, Ltd. 1970. vii, 104p. bibliogr.

A handy book which adequately summarizes the purposes of examinations in general, and of examining in physics in particular. Discusses educational objectives in physics at length before devoting more than half of the volume to a practical treatment of the construction and use of objective tests in physics.

Kruglak, H. "Resource Letter on Achievement Testing" in *New Trends in Physics Teaching, Volume II, 1970.* p. 405–429. Paris, Unesco, 1972. 517p. bibliogr.

With a brief introductory discussion of the nature of achievement tests in physics and the difficulty of measuring the complex variables of human abilities, the author gives an extensive annotated bibliography in the field of tests, examinations and assessment of achievement in physics. The ninety references, dealing with work done in the United States, are divided into six sections ranging from background references, theory and technology, physics achievement testing to various research efforts.

Lauwerys, J.A. and Scanlon, D.G. (eds). *The World Yearbook of Education, 1969: Examinations.* London: Evans Brothers Ltd., 1969. xii, 404p.

This yearbook contains eight sections of detailed exposition on trends, purposes, techniques and effects of examining. Of particular interest are: Section IV dealing with the organization and structure of examinations in different countries, Section V which looks at selection for education by examinations, Section VII which analyses effects of examinations on education, teachers and pupils, and Section VIII which looks into future prospects of examinations.

Lewis, J.L. (ed). *Teaching School Physics.* Harmondsworth, England: Penguin Books Ltd., 1972. 416p. bibliogr.

This Unesco source book contains contributions from many experts on almost all the aspects of physics teaching at secondary school level. Of particular relevance to assessment of achievement are (i) Chapter 17 which discusses in detail the aims and types of physics examination questions and (ii) Appendix B which gives details of various recent physics projects with emphasis on their objectives.

Macintosh, H.G. (ed). *Techniques and Problems of Assessment,* Arnold, 1974, 285p. bibliogr.

This practical handbook for teachers contains contributions on a wide variety of topics. Part 1 considers techniques of assessment, including structured questions, objective items, oral assessment, practical work and project work. Part 2 considers problems of assessment, including continuous assessment, assessment of attitudes, moderation, question banking, school based assessment, measuring attainment for curriculum evaluation. There are numerous suggestions for further reading.

Pearce, J. *School Examinations.* London: Collier-Macmillan Publishers, 1972. viii, 199p. glossary.

This book does not deal with any academic discipline in particular, but is addressed to all who attempt to assess students' achievement at school level through examinations. It presents a comprehensive exposition of the nature, methods, levels, coverage, grading and uses of examinations.

Polytechnic of Central London. *Examinations and Assessment.* The report of the working party, 1971. 92p. bibliogr.

This report deals with problems of assessment at the tertiary level, under the following section headings:– Assessment, The traditional written examination paper, The grading and classification of assessment, The assessment of students on sandwich courses, Student wastage, Assessment and student health, Assessment and the problems of change, Recommendations.

Rogers, E.M. "Trends in Testing" in *New Trends in Physics Teaching Volume II, 1970.* p. 431–447. Paris, Unesco, 1972, 517p. bibliogr.

This article is a powerful, penetrating exposition of the trends in, and social aspects of, examinations and tests with special reference to physics. The author points out the importance of examinations for students, teachers and the curriculum. He traces the origin and growth of objective tests and illustrates 'cruelty of examinations' with different purposes of 'entrance' and 'exit' examinations.

Rogers, E.M. *Improving Physics Education through the Construction and Discussion of Various Types of Tests.* Paris: Unesco. Report of a Workshop Seminar, 1972. iii, 119p.

This report is both a challenge and a guide to all who profess to construct physics examination questions and who engage in assessing student achievement in physics. Through critical discussion of actual questions constructed by experienced physics educators, the intricacies of physics testing are exposed. Invaluable material for any modern physics examiner and teacher at any level.

Stake, R.E. "Objectives, Priorities and Other Judgement Data" in *Review of Educational Research* (Washington, D.C., AERA), vol. 40, no. 2, April 1970. p. 181–212.

The first section, "Judgement and Data", of this stimulating review emphasises the importance of objectives as predetermined targets in educational programmes. The subsection 'What Educators should do' is the minimum that an impatient reader should digest in order to throw light on the role of objectives in influencing outcomes and making judgements.

Thorndike, R.L. (ed). *Educational Measurement.* 2nd edition. Washington, D.C.: American Council on Education 1971, xx, 768p. bibliogr.

The theory and practice of measurement of academic achievement are fully treated. Physics educators cannot meaningfully assess student achievement without fully understanding at least the substance of chapter 2 (Defining and Assessing Educational Objectives), chapter 9 (Performance and Product Evaluation), chapter 10 (Essay Examinations) and chapter 17 (Measurement in Learning and Instruction).

Unesco. *A Survey of the Teaching of Physics at Universities.* The Netherlands, 1966. 396p.

A Unesco resource book which treats in some detail several aspects of physics education at university level in U.S.A., U.K., U.S.S.R., Czechoslovakia, Federal Republic of Germany and France. Several appendices give notes on educational systems, physics syllabuses and specimen examination questions in these countries. The book generally emphasises the unity of physics as a discipline and the diversity of objectives and approaches to the teaching of physics.

Yus'kovich, V.F. (ed). *Methods of Teaching Physics in Soviet Secondary Schools.* Jerusalem: Israel Programme for Scientific Translations, 1966. 183p.

The Soviet publisher's annotation of this book needs no further comment and is quoted below:

"This book discusses the methodological aspects of teaching physics in secondary schools. The most topical among these are the present state of the method of physics, the development of the reasoning ability of students during the study of physics, and the experimental testing of physics teaching methods. The volume is intended for scientific workers and secondary school teachers". p. iii

12.20. REFERENCES AND NOTES

1. Houston, J.G. *The Principles of Objective Testing in Physics.* London: Heinemann Educational Books, Ltd. 1970. p. 23.
2. Klopfer, L.E. A chapter on Science Education in the *Handbook of Formative and Summative Education* edited by Bloom B.S. et al. 1971. New York: McGraw Hill.
3. Unesco. *A survey of the Teaching of Physics at Universities.* The Netherlands, 1966, p. 28.
4. Ibid. p. 28.
5. In the past seven years, new physics courses for secondary schools have been developed by: (i) The Science Teachers' Association of Nigeria, (ii) The Nigerian Educational Research Council and (iii) The Comparative Education Study and Adaptation Centre of the University of Lagos.
6. Federal Republic of Nigeria. *Second National Development Plan, 1970–74.* Lagos: Federal Ministry of Information, 1970. p. 236.
7. Unesco op. cit. p. 75.
8. Physics is compulsory for all students up to secondary school level, no matter what his future vocation may be.

9. John, J.B. and John, S.R. *Assuring Learning with Self-Instructional Packages.* New York: Self-Instructional Packages, Inc. 1973.
10. Chapman, B.R. "Assessment and Science Education". *School Science Review,* 55, no. 191, Dec. 1973. p. 380–385.
11. Lemaitre, M. and Verhaegen, L.A. *An experiment on the consistancy in marking of essay type examination in physics* (background circulated at the ICPE conference, Edinburgh, 1975).
12. McDaniells, D.K. "Discreet Grading System for Physics Examinations". *American Journal of Physics,* 41, 1973. p. 901–905.
13. Bryant Jr., N. and Hans O. Anderson. "Effects of Performance Objectives on Achievement". *Journal of Research in Science Teaching,* 9, no. 4, 1972. p. 369–375.
14. Bridgham, R. "Ease of Grading and Enrollment in Secondary School Science II: A Test of the Model". *Journal of Research in Science Teaching,* 9, no. 4, 1972. p. 331–343.
15. Rogers, E.M. *Improving Physics Education through the Construction and Discussion of Various Types of Tests.* Paris: Unesco, Report of a Workshop Seminar, 1972 (See annotated bibliography above).
16. Barnhill III, M.V. "A Self-Paced Approach to Graduate Quantum Mechanics". *American Journal of Physics,* 41, 1973. p. 661–663.
17. Barnhill, III, M.V. "Advantages of Review Examinations in the Keller-Plan Courses". *American Journal of Physics,* 42, 1974. p. 70.
18. Houston, J.G. op. cit. p. 23.
19. Rogers, E.M. op. cit. p. 3.
20. Houston, J.G. op. cit. p. 23.
21. Houston, J.G. op. cit. p. 23.
22. Houston, J.G. op. cit. p. 35–42.
23. Kruglak, H. "Resource Letter on Achievement Testing". In: *New Trends in Physics Teaching, Volume II, 1970.* Paris: Unesco, 1972. p. 405–429. (See annotated bibliography above).
24. Oguntonade, C.B. "Two Contemporary Issues in Science Education". *Journal of the Science Teachers' Association of Nigeria.* 11, no. 4, May 1973, 20–22.
25. Oguntonade, C.B. *In-service Course for Secondary School Science Teachers in Nigeria: Course No. 1, 1972: A Report.* Lagos: Unesco and Federal Ministry of Education, Dec. 1972, p. 27–67.

13 Integrated and multidisciplinary curricula at the secondary school level

This chapter, based on the paper written by G. Delacôte, deals with recent developments in secondary school science courses which are not confined to a single subject. The areas which are common to all the sciences and those which are different are considered, and a working definition of integrated science teaching proposed. Arguments in favour of integrated science are analysed and difficulties likely to be encountered discussed.

13.1 INTRODUCTION

It would be quite impossible, in this brief chapter, to give an overall picture of world developments in integrated science teaching. Some idea of the importance of current trends may however be obtained from three recent Unesco publications [1].

13.2 DEFINITION

The integrated teaching of science stems from a dissatisfaction with the content and methodology of one particular discipline or a series of unconnected disciplines. Yet it would be unfair to limit the use of the term to describing merely the fusion of physics, chemistry and biology. We shall use the term to describe a wide range of activities such as the presentation of a science and its applications; a science and mathematics; two sciences linked together; science and technology; etc.

D'Arbon [2] mentions 34 different definitions of integration. From replies to a questionnaire he has produced the following definition of integration:

> "Integration, applied to a science course, means that the course is conceived and presented in such a manner that the pupil acquires the concept of the fundamental unity of science [3] and the awareness of the corporate approach to problems of a scientific nature, and that he is helped in the understanding of the role and the function of the sciences in his daily life. Such a course eliminates the repetition of areas belonging to the different sciences, and does not recognise the habitual frontiers between subject matter when it presents themes or topics of interest."

Such a definition rejects the separate disciplines taught separately or taught together as 'general science'. In this kind of integrated science the frontiers between disciplines disappear.

More recently, K. Frey [4] has attempted an even more precise definition: "A course or curriculum of integrated science is a system of learning which contains information *extracted* from scientific disciplines or *related* to them. From an overall didactic approach this information is restructured and made functional with a view to achieving educational ends."

And Frey comments: "The information *extracted* from scientific disciplines includes, for example, the concepts, the methods, the laws, the experiments, the technologies, the know-how, etc. The information *related* to scientific disciplines may be the entire economic, moral, political implications of science, its historical development, its aesthetic aspects, etc."

13.3 ARGUMENTS IN FAVOUR OF, AND ARGUMENTS AGAINST INTEGRATED SCIENCE

Behind the desire to develop an integrated science course is the concern for unity in moulding a child's mind. This implies a balance between the different sciences rather than a specialization in one science. Another reason for a unified approach is that the transference of ability and of skills is better developed by a course of integrated science. Some teachers assert that certain concepts are treated quite differently in different science disciplines and that simple coordination between disciplines is not enough to ensure uniformity of treatment.

There are also economic reasons for choosing integrated science teaching. Certainly in the early secondary school where time is short and teachers are in short supply, any attempt to teach physics, chemistry and biology could lead to repetitions or even to the abandoning of one or more of the science subjects.

Pedagogical reasons have also been put forward for integrated science teaching. In the early years of secondary education the pupil can be put off by having a large number of teachers. A single science teacher in contact with his pupils for a much longer time will be in a far better position to know them and so point them in the right direction. At this level the teacher should be more concerned with the children's intellectual development rather than the development of the subject.

Science education should aim to allow people to cope with change, as major changes are likely to occur twice or even three times during a lifetime. We should not therefore be concerned with a fixed body of knowledge many parts of which may become obsolescent if not obsolete within half a century.

Finally, integrated science teaching can develop the consciousness of relationships between the sciences and society much more effectively than any other kind of science teaching.

One argument against integrated science teaching centres around the nature of the sciences. The division into distinct disciplines results from the specific characteristics of each discipline. An analysis of these characteristics would encourage one to evolve progressively from an undifferentiated to a differentiated and separated approach.

Perhaps the greatest argument against the introduction of integrated science, however, is the fact that in many countries there are few teachers adequately qualified to teach the subject. Only a small number of universities provide suitable degree courses and few students opt for these courses when they are available. What is even more important is that many teachers do not *want* to teach a wide range of different subjects and are much happier teaching their own specialization.

13.4 PRACTICAL ASPECTS

In the end, neither integration nor separation is the aim, but rather how to help youngsters to come to terms with the world. How can we generate a science curriculum which contributes to this aim, and how are we to prepare teachers to teach within such a programme?

At the *early stages* of secondary schools the students should be given experience in the methods of science. At this stage we are concerned with the skills acquired through the process of learning scientific facts and not with the learning of facts themselves. The content of the course should be relevant to the immediate environment of the student. We cannot expect the child at this stage to see the common patterns between the sciences, although the adult scientist will recognise any particular topic as physics, chemistry, biology, etc. or perhaps a combination of two of them.

One possible organization to this end might be as follows:

Elementary School	child centred undifferentiated approach low level conceptualization, if any emphasis on processes and attitudes relevance to everyday life
Early Secondary School	still child centred few concepts, those central to all sciences emphasis on processes and attitudes relevance to everyday life strong connexion with everyday applications either single integrated science course or well coordinated science courses
Upper Secondary School	(a) for science based students – single discipline based courses, as open as possible towards – (i) other disciplines (ii) science and society (iii) world of the scientists (iv) technology (b) non-science based students – science education strongly emphasizing a close coordination or even an integration of the disciplines to one single unit, if necessary using team teaching.

13.4.1 Non-scientists

An education which concentrates on the demands of a constantly changing society and also the needs of the coming generations cannot be realised if it is limited to one science area. It is necessary to include major information from all the sciences, including their technical applications. The education must be one for the student rather than one for the development of the subject as such! Non-science based students are different from their fellow students at least in that they do not have the same interests in physics. Their preferences and talents lie in other areas, for example, arts, literature, history, sports, politics, philosophy or others, and in general they have very little interest in science for science's sake.

An extensive preparation is necessary for such a comprehensive multidisciplinary general course. Subject-valid content for such a course can only be chosen by someone with an extensive knowledge of the various areas. No one person, however, is likely to have the wide subject knowledge which is necessary. The subject training of a teacher is hard enough in one discipline and a physics teacher is unlikely to have the necessary biological or chemical or technical knowledge to construct a satisfactory multidisciplinary curriculum. This can only be done by a group of teachers, each a specialist in his own subject.

13.5 EVALUATION

It is essential to find out whether or not the objectives set for the teaching of integrated science have been effectively reached. Yet because of the rapid development of such schemes evaluation is particularly difficult.

The temptation rather is to launch more and more trials and to attempt to adapt schemes to the general aims of society. This has led to an unstable proliferation in the development of integrated science teaching.

It is, however, essential to attempt to evaluate more thoroughly the effects of integrated science projects before too readily encouraging others. There are many questions to be answered such as:

(i) Have the pupils acquired a unified vision of science?

(ii) Have they fully realised the social implications of science?

(iii) Have they fully realised the implications of relationships between science and technology?

(iv) Have they mastered scientific methodology all the better by virtue of their integrated studies?

(v) What is the impact of integrated science on the interest and state of mind of the learners?

13.6 INTEGRATION OF SCIENCE AND TECHNOLOGY

Although there is obviously a link between science and technology, the precise nature of this link is not always the same. Sometimes the technology comes before the scientific study, as in the case of the clock mechanism which was invented well before the time of Galileo or Newton. On the other hand, modern electronic circuits are only possible because of prior discovery of semi-conductor principles.

There is, however, a deep division between the two cultures of science and technology. The approach of the former is analytic, reductive and simplifying. In science one is trying to isolate a specific problem or phenomenon and to find a pattern which will lead to a model or theory. Technology by contrast is essentially synthetic, as it gathers together a whole range of different skills and insights [7].

Science is universal and technology is particularized. Newton's laws are and should be the same everywhere, but how you apply them and how you teach them will vary from culture to culture depending on the psycho-cultural make up of the students.

In attempting to produce a successful integration of science and technology it is necessary to look carefully at the objectives of each and then to try to fuse them into a coherent whole [8].

The thematic approach to integration is probably the most appropriate. One might start for example with an internal combustion engine and discuss both its principles, which rely heavily on science, and its construction, which is dependent on technology. The affect that such engines have on the environment should also be considered.

Two existing schemes are worth examining: a syllabus of applied sciences (Engineering Science) at the secondary level recently developed in the United Kingdom [9] and an initiative into science and technology being tried out experimentally in France [10].

13.7 CONCLUSION

In conclusion it seems that recent efforts at innovation in the teaching of the sciences and more particularly of physics have a tendency to move away from a single discipline. Various aspects of integration are proposed instead. It is not always certain that thorough reflection on the possibilities of this integration has preceded these efforts, nor that a serious evaluation has followed them. It is not certain either that the bulk of teachers are ready to adopt these new ideas, either from caution or because of their training. Certain of them even describe this effort as a *fashion* and wonder whether this fashion will not be out of date a few years hence. It would therefore be right to recall the definition of a desirable scientific attitude that the innovators should respect if their objective is to see such an attitude flourish amongst pupils: "It is the ability to wait for a conclusive answer patiently; it is the scepticism that stems from intelligent reservations and the maintenance of doubt, the respect for work done in the past, and a desire to question assertions coming from sources that are authoritative."

One must nevertheless continue to encourage the lucid and moderate efforts at integration or, less ambitiously, at coordination. Certainly the latter course will not distort the physics aspect of the teaching of science. We should also encourage the extension of physics courses so that they have greater contact with other fields of human experience.

13.8 REFERENCES

1. New Trends in integrated science teaching. Editor: P.E. Richmond – Unesco, Paris.

Volume I. Different authors attempt in this volume to define what an integrated teaching of the sciences can be and to justify these definitions. The work reports in particular the conclusions of the first congress on the integrated teaching of science which was held at Varna in 1968. We will quote the first conclusion: "The teaching of integrated science contributes towards general education, emphasizes the fundamental unity of science and leads towards an understanding of the place of science in contemporary society. It avoids unnecessary repetitions and permits the introduction of intermediate disciplines". The importance of such teaching is particularly underlined in the case of developing countries: "A nation with limited manpower and resources must establish appropriate educational objectives and integration of science offers many advantages towards achieving these objectives".

There are examples of science integration in various countries, as well as a summary review of a few sociological and psychological problems which innovators may come across in the integrated teaching of the sciences.

Volume II. (1973, 239p). This volume rounds off very neatly the previous one by investigating the different approaches to integrated science teaching from the primary stage up to university level. Stress is laid on the nature of the methodological objectives.and of the content of such teaching, on the possibilities of building an integrated programme starting from problems and/or materials of everyday life and on the diverse methods of evaluation in these new approaches.

Volume III. (1974, 227p). A resumé of the records of the international conference organized in 1973 at the University of Maryland, on the theme of the training of teachers to teach integrated science. Apart from raising specific questions, this book has the merit of asking such fundamental questions as: what science? for what school? etc.

2. Volume II of the preceding reference [1] p. 146.
3. Such a pupil would probably be further advanced in this respect than many scientists.
4. Frey, K. et al. The Concept *"Integrated Science Curriculum"* 10p. Background paper to the Exeter Symposium on Integrated Science, Exeter 1974. Institut fur die Padagogik der Naturwissenschaften an der Universitat kiel, Kiel, Federal Republic of Germany.
5. Hall, W. et al. Patterns. *Teachers' Handbook.* Longman and Penguin, 94p, 1973.
6. Cardwell, D.S.L. *Technology, Science and History.* Heinemann, 250p. 1972.
7. Simondon, G. *The method of existence of technical objects.* Editor: Aubier, 266p, 1969.
8. Martinand, J.-L. et Host, V. *Objective of technical activities of 6 to 14/16 year olds.* Private communication.
9. Hiles, D.A. and Heywood, J. *Teacher Attitudes to Project in A level Engineering Science.* Nature 236. March 10, 1972.
10. Delacote, G. *"Media" Revue 1974 – Technology and Science – "Should one approach them in an integrated manner?"* p. 1–2, no. 64, Dec. 1964.
11. Hecht, K. *Background paper* presented to ICPE 1975, Edinburgh.

13.9 GENERAL BIBLIOGRAPHY

AUSTRALIA

Fensham, P.J. and Fyfield, J.A. (1972). An integrated approach to the training of teachers. *Australian Science Teachers Journal,* 18 (2) 37.

Ramsey, G.A. and Dale, L.G. (1971). The plan for the Australian scheme of teaching sciences (ASEP): its bases. *Australian Science Teachers Journal,* 17 (3) 51.

CZECHOSLOVAKIA

Janas, J.. *Interdisciplinary relations between Physics and Chemistry at the basic nine year school.* Sbornik prace pedagogicke fakulty University, J.E.

Purkyne 1974: *History of interdisciplinary relations between Physics and Chemistry in Czechoslovakia, in compulsory schooling.* The current situation is also tackled (matter, weights, molecules, atoms, laws of conservation). The author advocates improvements in co-ordination between the teaching of physics and chemistry at this level.

Pekarek, L. *"Modern Physics and Integration Trends in Natural Sciences".* Pokroky matematiky fyziky a astronomie 1973, vol. XVIII, no. 2.

This article discusses the interactions between physics and other branches of the natural sciences – in particular those concerned with living organisms. Physics, as far as the area of study of the basic fundamental laws of matter is concerned, occupies a special place amongst the natural sciences.

FRANCE

Delacote, Goery. *A working party to do what?* Bulletin Soc. Francaise de Physique *13* 20, 1973.

This work describes the method used in France for experimenting with and developing a course which integrates science and technology at the Middle school level.

HUNGARY

Proposals concerning co-ordination of the teaching of the natural sciences. Fiz, Szem 23, 376–383, 1973 (Hungary).

Suggestions for the co-ordination of the teaching of the natural sciences at secondary level (15–18 years).

INDIA

Shah, K.B. *Science and Mathematics Education in Indian Schools.* Vigyan Shikshak, The Science Teacher, no. 4, vol. 17, Oct–Dec 1973.

Objectives specific to India's problems are borne in mind for the teaching of science in this country (agricultural knowledge, health and hygiene, techniques connected with production and local economy). Two models are envisaged, one in an urban area, the other in a rural area. The objectives of creativity and of autonomous thought are developed by learning science based on the practical aspects and actual experience of work more than on the discovery method, which needs too much time.

Wanchoo, V.N. Several principles inspiring the science and mathematics course in the secondary school in the plan for the schooling of ten year olds. Vigyan Shikshak, *The Science Teacher, no. 4, vol. 17,* Oct–Dec 1973.

ITALY

Fabri, Salcioli. L'insegnamento delle Osservaziono scientifiche nella scuola media. *La Fisica nella Scuola V no. 1,* p. 20, 1972.

The general teaching of science at middle school level for children aged between 11 and 13 years is examined, through 22 pupils' books, through a questionnaire administered to 200 pupils in Tuscany, and through professional interviews. The result is a fairly severe criticism of current teaching.

Feretti, M., Partesotti, G. Un corse sul'ensegnamento integrato e coordinato della fisica e delle scienze nel biennio. *La Fisica nella Scuola VI,* no. 1, p. 17, 1973.

Results of a seminar held at the University of Modena in order to attempt to co-ordinate IPS teaching (Introductory Physical Science 14–15 years) with biology teaching – see also la FISICA nella SCUOLA VII, No. 1, p. 3, 1974.

ISRAEL

Revue Methodica de l'Universite de Tel-Aviv 1974

Brith, Malka. *Programme for Primary schools.*

Vardin, Pinhas. *Physics and Chemistry in the average secondary school (13–14 years).*

POLAND

Sawicki, M. *Integration in Science Teaching Nowa Szkola No. 1, 1970.*

ROMANIA

Constantinescu, Emilia et al. *Institute of Pedagogical Research, Bucharest 1970.* Report on the teaching of Physics at school.

Relation of physics to other sciences and to technology.

UNITED KINGDOM

Richmond, P.E. Approaches to integrated science teaching. *School Science Review,* 55, 192, 1974.

Analysis of present day development of integrated science teaching in British schools.

Sayer, M. Technology appreciation. *School Science Review 54, 189,* 1973.

Technology must not be separated from other sciences.

Tawney, D.A. Technology in the Nuffield Advanced Science Projects. *School Science Review 54, 187,* 1972.

Education in Science (Bulletin for the Association for Science Education). *58,* 14, 1974. Examples of integrated science teaching (11–13 years old). Development of the SCISP programme. *51,* 23, 1973. Description of integrated lessons "Combined Sciences". *56,* 28, 1974. Dissemination of the SCISP programme.

UNITED STATES

Adams, T. *"A review of Unified science and the high school".* School Science and Mathematics *71,* 495, 1971.

History of unified science lessons and problems encountered.

Johnson, G. An integrated two year Chemistry-Physics Course compared with consecutively taught courses. *Science Education 56,* 143, 1972.

The comparative effect of two successive or intermingled courses of physics (PSSC) and chemistry (Chems.).

Zoller, Uri and Watson, F.G. *"Technology education for non-science students in the secondary school".* Sci. Educ. *58,* 105, 1974.

Suggests a technological teaching programme.

Dilavore, Philip. *"Physics of Technology.* A report of the Tech. Physics Project". Phys. Teach. *11,* 473, 1973.

Describes the 40 modules of this project for teaching physics in relation to a particular set of apparatus.

Gard, Paul. ECCP and the Urban Student: an activities approach. *Phys. Teach. 10,* 459, 1972.

Gives examples of activities in relation to the Technology Course "The Manmade World".

Herr, Lowell. "Unified Science: A solution to Physics Enrollment". *Phys. Teacher, 9,* 248, 1971.

Integrated course over five years (High school), Physics, Chemistry, Biology.

Hodges, Laurent. Environmental Topics for Introductory Physics Courses. Phys. Teach. *12,* 205, 1974.

Detailed examples of subjects connected with the environment and their integration into a physics course.

Liao, T. and Piel, E.S. "Let's get relevant". *Phys. Teach. 8,* 74, (1970.

Describes the ECCP technology course: "The Man-made World".

Manos, Harry. "Combining Mathematics and Physics in High School". *Phys. Teach. 10,* 385, 1972 and *12,* 151, 1974.

Example of mathematics and physics courses (High-school level) taught by the same master.

Wigley, E.J. The technological approach. *Phys. Teach. 10,* 8, 1972.

British programme (11–16 year olds) where the pupils carry out projects in small groups.

Savitz, M. "Science on Wheels". *Science Teacher, 40,*.37, (January 1973).

Experiments carried out by pupils to show the relationship between science, technology and the urban environment.

General Books

TEACHING SCHOOL PHYSICS. Ed. J. Lewis. Penguin Harmondsworth, UK, 1972.

One chapter (8th) concerns the integration of the teaching of physics with other sciences. Another (10th) concerns the relationships between physics and technology in general teaching.

SCIENCE AND EDUCATION IN DEVELOPING STATES. Ed. Philip and H. Gillon. Praeger Publishers, New York, 1971.

Examples of integration of science teaching in Latin America and Africa. The development of links between science and technology (social and economic aspects) in the U.S.A.

LEARNING TO BE. The world of education. Today and tomorrow. Unesco, Paris, 1972.

Particular emphasis is laid on the development of organic ties between the teaching of science and the teaching of technology.

14 Pre-service and in-service training of secondary school physics teachers

In the first part of this chapter, which is based on a paper by Maria Ferretti, present developments and trends are summarized. Different methods for training physics teachers in different countries are discussed and current and past methodologies are contrasted. The new trend of considering pre-service and in-service training as a long-life process for every physics teacher is reported.

Consideration is given to the importance of teachers' centres, the significance of the activity of physics teachers' associations, the implications of the widespread use of new technologies in both industrialized and developing countries.

The next part of the chapter deals with some problems and challenges and it concludes with a series of recommendations made by the working group.

14.1 INTRODUCTION

The lack of well prepared secondary school physics teachers appears to be a world wide phenomenon. A comparative review of training and retraining activities and the identification of general trends in this field can therefore be useful both to scientists and educators involved in such training, on the one hand, and to administrators and policy-makers at all levels, on the other. In recent years, teacher training activities have been strongly affected not only by the growing body of scientific knowledge, but even more by the achievements of educational theories and psychological research and by the growing impact of educational technology.

The employment of more and more sophisticated training techniques, and the increasing number of training institutions, should yield increasing numbers of well educated teachers. However, we suspect that good training alone will not be sufficient to give teachers the professional satisfaction they need. In order to avoid the widespread frustration of many teachers some status problems ought to be solved. This is necessary, at least in some countries to give them confidence in themselves and in the significance of their task.

The status problems are not often explicitly mentioned in national accounts of pre-service and in-service training of physics teachers [2], and some of them are related to the teaching profession as a whole. They range from low salaries, lack of incentives, lack of prestige, instability of personal position and lack of guidance at the beginning of their career, to poor organisation and lack of educational facilities and ancillary support in schools.

The present report will not deal explicitly with the problems of teachers' status. They, nevertheless, exist and must be kept constantly in mind as they are boundary conditions strongly affecting the actual possibility of improving the whole of the teaching profession in a country [3].

14.2 PRESENT DEVELOPMENTS AND TRENDS

14.2.1 Different Methods of Teacher Education

It is generally admitted that at different age levels, the methods of teaching have to be different, as they are tied to the psychological development of the pupils. They start from a mainly phenomenological and descriptive approach in the first cycle (11–14), and go on to the more abstract and deductive treatment, only applicable when the full stage of logical operations is reached. These different methods of teaching physics at different ages are also tied to the development of mathematical knowledge and skills.

The education of future physics teachers is divided into different levels (usually two) all over the world. For instance, in Belgium the physics teachers for the three lower classes of secondary schools are trained, for two years only, in special schools (*écoles normales*); in Hungary, in spite of the fact that even in the 'upper primary' physics is taught as a separate subject, teachers for this kind of school are trained in training colleges for three years, whereas the teachers for the second cycle are prepared in universities. In Israel the first two years of a university course for teacher training are required in order to teach physics in the middle-schools (lower secondary), while the complete four-year course is necessary for high-school teaching. Similar patterns may be found in Japan, New Zealand, Spain and Jugoslavia [4]. In the Federal Republic of Germany, a five year university course is required for teaching physics at the higher level, while three years in a teacher education college are requested for the 10–14 level. Eighteen months practice after graduation is necessary in both cases.

In other countries, no less than a four-year university course is required for teaching physics even at the lowest level of secondary instruction and this depends, of course, on previous school physics courses. In Italy, for instance, a four year degree is required, but while this must be in physics or mathematics in order to teach high school physics, in the lower classes (*scuola media*) a teaching certificate in science (physics being a part of an integrated science-with-mathematics course) may also be granted to a wide variety of graduates, for example, in chemistry, biology, mathematics. Similarly, four years of university leading to graduation are required in Egypt and various other Arab States, Ethiopia and Brazil, and as far as we know, in the majority of the third world countries. In Denmark, six years are needed for the training of grammar school physics teachers. To get a correct idea of the content of these university courses and of the depth of treatment of the subject matter, a detailed analysis would be necessary, but this is outside the scope of the present chapter.

In general, colleges of education offer courses centred more on educational subjects, while the teacher training in universities is more physics-centred. For this reason, university graduation in physics is generally linked with post-graduate educational and professional training. After graduation in France, one year is devoted to practise teaching in schools by teams of three students at a time, under the supervision of a senior teacher (*conseiller pedagogique*) [6], and the same method was also used in Belgium. Now a reform is in progress in France, with the institution of the *Centres de Formation des Maitres* [7], similar in some respect to Teachers' Centres. One year's training after graduation is required in Israel, Spain and Scotland and such a course is common in England and Wales. In Denmark, a six month course is required.

A period of professional training after graduation (at least one year) is of particular importance when graduates are not physics specialists. The demand for graduates in scientific careers is steadily decreasing in industrialised countries, while at the same time mass instruction and the rising level of compulsory education tend to produce increasing numbers of them. Some are likely to seek entry into the teaching profession as a remedial solution. They will not be suitably prepared to teach physics either by their subject centred education or by any strongly felt personal interest [9, 10, 11]. A year's training in professional and educational subjects before the year of induction into the profession will be a real social necessity.

For their part colleges of education tend to give longer and deeper subject preparation to reach a level which could stand comparison with university standard in addition to concurrent professional and educational training.

A typical example from the English colleges of education is a concurrent course joining subject studies with education and methodology leading to the award of the Bachelor of Education degree and to qualified teacher status [12]. The whole course of study may last three or four years and each student is supposed to work in three main areas: professional studies, educational studies, subject studies. Practical experience in a variety of schools will be provided as an integral part of the course in professional studies. The B Ed honours degree will lead to the same initial salary as the traditional university degree plus the Postgraduate Certificate of Education. For the pass course, lasting three years, a model of a concurrent programme based on 18 hours a week could be [13]:

1. Major subject (physics): 500 hours
   Minor subject (possibly chemistry or mathematics?): 200 hours
2. School experience: 250 hours
3. Professional studies: 400 hours
4. Education studies: 300 hours

The physics programme should include, in addition to the specific topics, suitable mathematics courses, the history of physics, and some application of physics to other natural sciences. The professional programme should aim at different specific activities such as the use of new teaching techniques, laboratory organization, maintenance of equipment and construction of simple apparatus, use of different kinds of teaching aids (including computer-assisted instruction), preparation in various assessment procedures [14] and the use of evaluation methods. Educational studies will include psychology and sociology, suitably blended with teaching methods.

Courses of this kind follow the recommendations of the Eger Conference [15] and the conclusions of the James Report on education in England and Wales [16]. The Report analyses the general situation in England, and formulates a number of proposals to improve the training of teachers at the secondary level. Many of the statements of the James Report, reflecting present-day trends in the policy of teacher training in general, can on the whole be endorsed and applied to the training of physics teachers as well.

In the United Kingdom, an increasing number of universities are now offering joint science-with-education degrees [8, 17] on the lines proposed by the James Report. A similar procedure has been adopted in Italy, where a choice of university courses, including educational studies, is offered to intending teachers. Reasons for this trend, by no means restricted to those two countries, are not only the improvement of the quality of teacher training but to meet student demand for more general and socially oriented courses.

In fact science in general and physics in particular are now less popular than in the early sixties. The 'swing from physics' is a general phenomenon. In high schools young people are inclined to show less interest in scientific subjects, particularly physics, which is perceived as a detached study of the natural world, based on unreal assumptions and far from the human implications of present-day life and, what is worse, responsible for all the evils of the past and present (war, pollution, food and population problems, and so on).

Student unrest has been heavily based on these assumptions and one of the results is that, typically, in the U.K. the biggest growth point in recent years in academic sixth-forms has been in the percentage of students taking mixed science/arts A levels [8]. An analogous trend can be found practically everywhere in industrialized countries. It is hoped that science-with-education degrees may help to span the art/science divide. They are vocational degrees but, as in Italy, they do not restrict their graduates to school-teaching even if the majority of graduates do in fact teach. The result of this kind of degree should produce not only an increasing number of well qualified science teachers, but possibly open a number of new careers in addition.

14.2.2 Training Methodology

At the beginning of the last decade the training methodology for physics teachers almost everywhere in the world appeared to be rigidly traditional. In every subject formal lectures were the main teaching method, not only for scientific courses proper, but also for the educational ones. In some countries, practical work in schools was non-existent or very limited and haphazard. Of course there were important exceptions (for instance the practical courses in the Federal Republic of Germany [4] and the 'stages' in France and Belgium [6]), but the general trend was to teach intending teachers mostly with 'talk and chalk' methods, even when they were encouraged not to teach with 'talk and chalk' in their future profession.

This was, and still is, particularly true in developing countries, partly due to the educators of the intending teachers frequently being foreign teachers themselves. Often they were not well acquainted with the habits and the local resources of the country, and frequently not even able to speak the local language [19]. The importance of this phenomenon can be inferred from the following figures [20]: in 1968 the Development Assistance Committee of the OECD provided the services of 1161 teachers for teacher training, mostly from industrialized countries. The United Nations Development Programme is also supplying personnel for teacher training: many secondary school teachers in the Arab countries, for instance, come from Egypt [19]. These contributions to the local teaching staff are essential, because of the shortage of physics and science teachers. In developing countries, this shortage has different origins from those in industrialized countries, being caused predominantly by a sort of 'brain drain' inside the country itself, which favours technological and administrative careers to the detriment of teaching.

The impact of the new physics curricula

The development of the new curricula for secondary school physics teaching, which has characterized the last decade, has proved of great value for training teachers as well. A critical study of PSSC, Project Physics, Introductory Physical Science and the various Nuffield projects (to quote only a few) was easily introduced into traditional training courses, since most of the material was available and sufficiently cheap. For the trainees the beneficial effects of this kind of work were rapidly obtained and had a lasting influence on their teaching afterwards.

A very remarkable course for a teacher training college, based on one of the new proposed curricula (IPS) has been developed by the IPS group led by Uri Haber-Schaim [21], presently at the School of Education of Boston University [21, 22]. In this course, science and mathematics subjects are planned in a definite sequence (following the College edition of the textbook produced at the EDC [23]); the other topics can be taken at a variety of times, but the most important feature is the emphasis put on laboratory work and discussion of physics problems, only one tenth of the whole planned time being devoted to formal lectures. Subjects range from physical science (a two year course) to experimental physics, experimental chemistry, chemo-physics, theoretical physics, workshop practice, testing and measurements, native language, practice teaching and educational psychology. Among the electives a foreign language is strongly recommended. Most importantly the general strategy is based on the assumption that teachers teach the way they were taught, and the whole programme is therefore consistent with modern ideals of good school science teaching.

Another outstanding example of pre-service teacher training material is the last enterprise of the Nuffield Foundation, known as the STEP programme. This project used over 200 tutors in colleges of education for the preparation of exercises intended to promote group activities for student teachers. The purpose of these activities was to help the transition from the role of student to the role of teacher, and at the same time to show how ideas from psychology, philosophy etc. can be used to help solve classroom problems. The activity of STEP started in 1970 and, from the beginning, the trial material aroused world-wide interest. It has been used in Australia, Hong-Kong, Israel, Nigeria and the West Indies. Recently all this material has been published [33]. It consists of a series of activity books, resource books and enrichment material (slides, film-loops, video- and audio-tapes, simulation exercises, discussion papers). The materials from these important new curricula were not so widely adopted in the developing countries as might have been expected. The reason is not only to be found in the lack of information, nor in lack of goodwill on the part of local teachers, nor in difficulties relating to language barriers, but much more in the fact that courses designed for students in technologically advanced countries assume a background of experience and of concepts not always shared by the students in developing countries [24]. However, there is a steady trend to adapt those courses to local conditions and, in general, translations of recommended books into local languages are officially encouraged [25].

14.2.3 In-service Training

One of the main characteristics of the James Report already quoted is the greater prominence given to in-service education compared to pre-service education. The reason for this unusual approach is worth serious consideration: most would agree that "any proposal to improve the methods by which a profession acquires new members must take a long time to become effective. Meanwhile, established members of the profession need opportunities to improve their professional status and standards. It is no accident that teachers who are at present outstandingly effective and successful have a clear understanding of their professional aims and enjoy a high degree of satisfaction in their work tend to be those who have had the benefits of in-service opportunities to extend their personal education and personal skills" [16]. Experience all over the world shows that this is particularly true for physics teachers [26], and it confirms the general trends, even more emphatically outlined by the Faure report [20]. "The transition from the idea of initial training to that of continual education is the mark of modern pedagogy. Conditions in which teachers are trained should be profoundly changed so that they become educators rather than specialists in transmitting pre-established curricula; the principle of a first training stage followed by in-service training cycles should be adopted". Still more clearly the James Report concludes: "Initial higher education, pre-service training and induction, and subsequent in-service training of teachers have to be regarded as consecutive parts of a continuing process in which all parts are indispensable, and, although separate, interrelated".

The variety of approaches

So far, there is an almost infinite variety of approaches to the in-service training of physics teachers, ranging from the most informal and loosely structured discussion groups, to the highest level of formal post-graduate studies. They can be organized by very different bodies (ministries, local authorities, universities and colleges, 'teaching centres' and teaching seminars, teachers associations and even industries) and may be widely different in format and duration. Full-time courses can last a day or a few weeks, or even a whole term. Part-time courses can last for part or the whole of a school year with only a few periods a week. These courses may be concerned with content or methodology or both. It is interesting to note that a number of in-service courses are focused on some inter-disciplinary study to bridge the gap (or the supposed gap) between science and the humanities [27]. From the Eger conference recommendations and from the James Report it appears that a minimum of one week of in-service training a year and one term (12 weeks) every seven years for serving teachers is essential.

In some countries, in-service training courses are compulsory, but more frequently they are left to the free choice of the individual teacher on a voluntary basis. If the in-service seminars are not held during summer vacations, schools must find replacement teachers and this may involve some difficulties and consequently some resistance from the school administration. On the other hand, as in-service training is considered more and more a duty rather than a right, these kinds of difficulties will have to be overcome.

A remarkable case is provided by Hungary [4], where teachers have many different ways of taking part in in-service training courses: the participation is not compulsory, except for the course organized yearly by the Ministry .for inspectors. It has to be taken every year, at the national Institute of Education, and lasts three days. During these courses inspectors give reports on the conditions of physics teaching in their district, and collect information and advice for the next school year.

The induction year

The first step in in-service training is the first year in the teaching profession, after certification. In England this is referred to as the 'induction' year. According to the James Report, it is the most important period in the whole of the professional life of a young teacher, who must be given particular help and support both by experienced school staff and by tutors. At the present time, several local authorities are conducting experiments to find the best methods of providing this help and support. This problem is present in many countries, and its solutions are very much dependent on local school organization: general solutions are impracticable. A particularly effective suggestion is to introduce teachers in their first year of professional work to local organizations known as 'Teaching Centres', as indicated by D.A. Tawney [28].

14.2.4 Teaching Centres and Teaching Groups

Teaching Centres are often organized at the training institutions and have the important function of providing teachers with a meeting place where they can overcome the frustrating sense of isolation which is one of the most serious drawbacks in the teaching profession.

In many places some 'teachers' groups' are also starting: they are organized by teachers for teachers and their importance is considerable. Their limitation is that they can reach only a comparatively small number of teachers so that their impact on the improvement of the quality of teaching in general remains quite modest.

In Japan, science education centres were first established in 1960; ten years later about forty were already in operation all over the country and their number seems to be increasing. In-service training courses are compulsory for all Japanese teachers. As elsewhere, in-service courses are also organized by industries, local authorities (prefectural offices), the local physics society and so on [29].

In the USSR, re-training has been a huge problem, as there are about 80 000 physics teachers:

a solution has been provided through the foundation of 180 state institutions for re-training, with courses compulsory for every Soviet teacher at least once every five years [30].

Some examples

In some countries, and especially the developing countries, in-service training is valued by some teachers as a means towards earning more money or enjoying more prestige. This may occur no matter whether their teaching performance has improved or not [31].

Nevertheless, some of these countries have provided outstanding examples of in-service training with excellent results. One example is the African Primary Science Programme, working since 1965 and developed with assistance from the Education Development Center, Massachusetts, operating under a US/AID contract. The material produced is the result of the collective ideas and classroom experience of many people in several African countries: Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Tanzania and Uganda. An analysis of Nigerian science teachers' opinions on an in-service course held in 1972 was presented by C.B. Oguntonade at the first annual conference of the Sierra Leone Association of Science Teachers (July 1974) [26].

In the Caribbean Islands, a Science Educators Workshop on integrated teaching for children between 11 and 15 years was held in October 1973 under the joint auspices of Unesco and CEDO (Centre for Educational Development Overseas, U.K.). The results are impressive. The final report (ISTE) is a small encyclopaedia, where all the main features of any possible teacher-training activity are presented, critically discussed, and applied to the local conditions of life and work [32].

14.2.5 A Few Words on Educational Technology

In the preceding sections there has been no room to consider 'educational technology' separately from general teacher training. In fact, it appears that in many cases, physics teachers are still trained as they were thirty years ago as far as educational technology is concerned. Many of the newer techniques, however, can help physics teachers to perform their task more effectively in novel conditions. How is it possible to deal with audiences of 600 pupils? How can pupils be prepared to pass a national exam if they live in isolated Australian farms? How can teaching in classes of widely different abilities be individualized? How should we deal with slow learners? How can we encourage talented pupils?

A number of new teaching techniques and technological devices can help to provide answers and their use is growing. At present, however, their use is confined to unusual situations and it is difficult to generalize about their merits and their shortcomings. How much of the excellent results of some new techniques are intrinsically bound to the techniques themselves and how much to the involvement and to the eagerness of an enthusiastic pioneering teacher? Some micro-teaching techniques appeared to fail in the African workshop [31] while they were reported to be successful in the Caribbean [32].

Physics teachers should be trained to use these new methods of teaching critically. They should also be encouraged to provide the much-needed fundamental feed-back.

The danger of 'dehumanizing' [34] the teaching activity using technological devices (computer-assisted instruction, video-tape recording, programmed learning, overhead projector, polaroid cameras and so on) is not in the devices themselves, but in the way they are used. Their merit is in the broadening of the possibilities open to the teacher and this is true for every subject, not only for the teaching of physics. One of the difficulties of their use in teaching physics proper concerns the laboratory activity: this is always to be kept in mind when designing new teaching aids for training physics teachers. Let us then add a word of warning: even the new technological means can be used like the blackboard in the 'talk and chalk' method. Film loops shown without stimulating pupil involvement can be as dull as any unfortunate blackboard sketch.

An interesting example of a multi-media approach, which apparently can also be used for physics teachers' training is the autolecture/seminar, developed first by Breme and later by Baez in summer courses at Harvard University [35]. The system consists essentially of lectures divided into two phases of equal duration (about 45 minutes each): the autolecture and the seminar. Stimulation is provided by the autolecture, which employs audio-cassettes channelled through a high-fidelity recorder plus an overhead projector. All the 'software' (or shall we call it 'teachware'?) can be prepared by the instructor beforehand, and then duplicated at will. Copies of the transparencies and notes are handed directly to the students. The seminar provides the opportunity for discussions, critical study, and individualized teaching. This technique makes it possible to deal with large classes and to proceed at each student's individual pace. This is a striking example of an approach strongly based on personal relationships (through the notes and the seminar activity) even if the individual tools are 'cold' technological devices.

The mass-media (television, radio broadcasting) can also be invaluable aids in providing in-service facilities for training teachers. The Open University in the U.K. is perhaps the most impressive example of integrated mass-media and technological devices, combining television and radio programmes with home study and short intensive instruction periods in summer schools. About 25 per cent of the 40 000 enrolled are serving teachers [34].

However, as far as the mass media are concerned there is also the danger that an improper use of their powerful influence could result in an authoritarian and dogmatic instruction and, in the last resort, transform them into a means of ideological pressure. This aspect could be even more serious in the case of teacher training, since the consequences grow exponentially.

Before ending this too rapid survey, we must remind ourselves that the most ancient technological visual aid, the book, still deserves an honoured place, and that the logical operations connected with the personal (and original) reflection on the content of the written page cannot be entirely replaced by the language of images alone. Therefore a physics teacher's preparation could not be complete without training in reading and discussing some of the original works of outstanding physicists of the past and the present time. The planning and the maintenance of a class or school library, and its daily use, has also to be learned and widely practised. There must be a reasonable number of specialized periodicals on the teaching of physics, and possibly of other sciences, to get teachers acquainted with the latest developments and trends.

14.3 SOME PROBLEMS AND CHALLENGES

In the previous sections, many problems have emerged. We would like to summarise at least some of them.

A number of these problems are connected with the foreseeable evolution of our social life: (1) the request for more instruction by broader layers of world population will require increasing numbers of teachers; but, as the average scientific instruction is likely to be more on the line of 'integrated science' (at least at the lower levels), more teacher training in integrated sciences will be necessary. (2) A 'technological literacy' will also be necessary in the training of physics teachers as our physics teaching is moving away from being purely 'physics for physicists' towards more applications in 'physics for action' and also more significance as 'physics for citizens' [36]. (3) Following the trend for 'continuous education' for everybody, teachers have to be instructed on how to deal with adult education and with the education of the slow-learners and handicapped children. (4) Every effort has to be made to overcome the isolation of physics teachers, even inside a single school.

But the most important problem that we have to consider is the training of *physics* teachers. Of course, we are well aware that the 'swing from physics' of the younger generation may be motivated by the general dissatisfaction of students who are at present sensitised to the social aspects of the problems underlying our everyday life: the huge problems confronting humanity at the present time do not appear to have very much to do with the elaboration of abstract physics theories. But it is no less true that the higher intellectual standards that can be reached by scientific speculation are an important challenge for some of our students and we have not the right to deprive them of this intellectual challenge. The difficulty of the task should not prevent us from trying if we are convinced that the development of physics has been of essential importance in the construction of our modern civilization itself and that the best values of modern civilization are worth defending and developing.

This holds even if we are considering the present trend toward the teaching of integrated sciences in schools and the humanistic presentation of science itself. Indeed the central position and the unifying power of modern physics, both from the theoretical and the methodological point of view, makes the study of physics not merely useful, but necessary for any sufficiently deep understanding of the nature of modern science as a whole and of its spiritual values.

This challenge throws a special light even on the much more limited problem of the preparation of the staff for physics teacher training courses and particularly for the pre-service ones. Physics courses for future teachers should in fact have a different character from courses designed for potential research physicists. Their theoretical content should not only be continuously related to secondary school physics, but should be framed in a historical structure, showing both the development of fundamental concepts themselves, and their relevance for the unification of all the sciences (from astronomy to chemistry, to molecular biology and so on).

14.4 SOME PRACTICAL SUGGESTIONS

14.4.1 Pre-service Training

The working group at the Edinburgh Conference considered that the following items should be included in an education course for physics teachers:

(a) A study of fundamental physics principles, laws and concepts organized so that students become familiar with the methods of scientific research, experimental work as well as theoretical reasoning. This part of the course aims at giving students a sound understanding of the topics they are going to teach at school level and provides a background which makes it possible for them throughout their careers to keep up to date with physics and physics education through reading journals and books.

(b) A study of how scientific thinking has developed and of the social and technological importance of science. An example of the materials which could be used for this study is the correspondence between Ampere and Faraday on electromagnetism which illustrates well two different conceptual approaches to the same problem.

(c) A training in the following skills (not in order of importance):

1. organization and guidance of students' laboratory work,
2. preparation and execution of demonstrations,
3. evaluation, purchase and maintenance of laboratory equipment,

4. organization of different forms of learning (lectures, discovery and inquiry methods, structured and open-ended activities, self-instruction methods, etc.),
5. assessment procedures (for example, the preparation of and the marking of fixed response and free-response tests, essays, oral assessment, assessment of experimental skills, of project work).

(d) A comparative study of the various ways in which different topics may be treated at different ages and different levels of ability. This might include (i) a study of selected parts of recently developed physics curricula illustrating their different aims and methods, (ii) a small project in which the student himself develops some curriculum materials.

(e) A study of general educational theories, related to problems of physics education and of psychology, focused on the learning abilities of pupils at different ages. It was suggested that seminars conducted jointly by a social scientist or a philosopher and a physicist might help to relate general educational theories to problems in physics teaching.

(f) Practical experience of school teaching under the combined guidance of experienced school teachers and of college or university staff. Students should be introduced gradually to teaching, for example by giving demonstrations to their fellow students, teaching fellow students, micro-teaching, group teaching, working with an experienced teacher and taking parts of his lessons or parts of his classes. Audio or video tape recorders might be used so that students could play back their attempts at teaching. Efforts should be made to sharpen students' understanding of inter-personal relationships and to make them aware of the importance of their attitudes towards their pupils.

14.4.1.2 University and College Teachers

It is highly desirable that the college or university teachers responsible for guiding the education of future physics teachers should not only have the qualifications in physics but also considerable experience of physics teaching at school level. Throughout this education, the methods used should be such as to develop in students the keenness and the ability to continue to learn throughout their teaching careers.

The education of future physics teachers at universities ·

University physics courses are designed predominantly for future research workers; this emphasis contributes to the low prestige of school physics teaching and may lower the confidence of those who subsequently become teachers. While the group was agreed on the problem, it could not recommend one single solution; some members felt that an educational *component* in a physics degree course should be of value to future research workers as well as future teachers in helping them to communicate with others about their work; others felt that an educational *option* was a possible solution (as at the University of Leeds); one university (MacQuaine) had designed its physics course specifically for future teachers, and future research workers were the anomally; others felt that in their countries it would be unrealistic to try to change degree courses in these ways.

The education of teachers at colleges of education

It was thought that in some countries there was a trend towards placing more emphasis on the subject (that is, on physics itself at the expense of the education component). In each situation the relative proportions need to be studied to ensure that the balance is optimum.

14.4.1.3 The Influence of Local Conditions

It was emphasised that any attempt to follow the recommendations given in this chapter must take into account local conditions. It was realised that in developing countries, for example, a shortage of teachers at all levels might lead to a curriculum very different from that given above, with perhaps more emphasis on teaching physics with very simple apparatus constructed from inexpensive materials readily obtained locally. However some felt that the construction of equipment out of everyday materials should be considered as part of the education of teachers in developed countries as it encouraged them to be inventive themselves and to provide creative work for their pupils.

14.4.1.4 Teaching at Different Levels in Secondary Schools

There was a difference of opinion as to whether it was desirable to educate only one group of teachers to teach at all levels in secondary schools or two groups of teachers – one responsible for the higher level, the other for the lower. In practice the solution depends on local conditions and educational traditions.

It was recognised that the growth of integrated science teaching in the first years of secondary schools was making it even more difficult to prepare teachers with a sound grasp of the subjects they were expected to teach.

14.4.2 In-service Training

Recent changes in physics education, such as the introduction of new teaching methods with an increased emphasis on experimental work and the introduction into school courses of more sophisticated theoretical concepts, made in-service training a necessity. No single pattern could be recommended: many forms of in-service training existed, and coexisted even in the same locality.

The group at the Edinburgh conference recommended very strongly that teachers should have adequate incentives to attend in-service courses; at the very least their expenses should be refunded in full. In the U.S.A. teachers attending summer schools are given 'credits' which are taken into account for salaries and promotions. In Denmark, teachers attending courses have their teaching time reduced.

In some countries the factor limiting in-service courses is the provision of replacement teachers.

Members from developing countries expressed the view that Unesco should do more to develop in-service training, perhaps by providing the funds which a country needed to organize its own courses rather than organizing regional courses itself. A depressing note was sounded by some members who reported that no matter what provision was made and what incentives were provided, a substantial proportion of teachers never came to in-service courses on a voluntary basis.

14.4.3 Teachers' Centres

Teachers should be encouraged to meet together in teachers' centres. Centres organized by teachers themselves are much better than centres organized by central authorities, universities or higher education institutes, as teachers' groups can obtain tutorial help from highly qualified university staff in less formal but much more efficient ways. In this kind of organization budgets can be kept at a quite modest level.

14.4.4 Isolation

In addition to the physics centres already mentioned, two steps could be taken to help teachers to overcome their tendency to isolation. First, the GIREP survey could be broadened and improved [4] through a wider co-operation involving the largest possible number of countries possibly with the help of Unesco. Second, an International Directory of all periodicals and journals (including the most important newsletters) dealing with the teaching of sciences in general and physics in particular should be prepared and possibly sent to schools and teaching centres.

A similar directory for the existing science or physics associations could prove useful [38]. Wherever possible, national associations and individual schools (in addition to single interested teachers) ought to be encouraged to join other associations. For this, slight modifications of the statutes may be necessary in some cases. Members of the different associations present at the conference might be urged to study the possibilities, possibly with the help of Unesco.

14.5 CONCLUSION

In conclusion, we would recall that any teacher education activity is strictly tied to the political choice shaping the school systems in any one country. These choices are not only determined by the declared aims of secondary education, but also by some existing constraints like the extent and duration of compulsory education, the industrial and economic pattern of the country, its traditions and its cultural background.

The general conclusions and recommendations of every international report must therefore be sufficiently flexible to be adapted to rather different situations; but in any case individual teachers must also be trained to make their own choices of methods and content for use in a world in which new balances between knowledge in specific fields of scientific investigation and the uses and implications of this knowledge are painfully sought by the younger generation.

14.6 BIBLIOGRAPHY

1. Eurin, M. La formation des maitres de l'enseignement du second degré. In: *New Trends in Physics Teaching.* p. 185, Paris, Unesco. 1965–66. 271p.

2. The Japanese National Commission for Unesco.
Training of Science Teachers in Japan. 1970, p. 147.
Matta, K. and deSa, B. Remarks on the Standard of Secondary School Students in physics and mathematics in Libya. In: *Survey of Literature on physics education.* Edinburgh. International Conference on Physics Education, 1975.

3. Brown, S.C., Kedves, F.J., Wenham, E.J. Constraints in Teacher Education. In: *Teaching Physics. An Insoluble Task?* p. 22–35. M.I.T. Press, Cambridge, Massachusetts. 1971, 261p.

4. Groupe International pour l'Enseignement de la Physique. *School Systems Survey.* In progress.

5. Organisation Européenne de Coopération Economique. Organisation de l'Enseignement dans les pays de l'OECE. Diagrammes et glossaires. p. 89. Extraits de *"L'Éducation dans le monde"*, vol. II, 1958, Unesco, Paris.

6. Ministère de l'Education Nationale. Direction Générale de l'Organisation et des Programmes Scolaires. *Organisation et Fonctionnement des Centres Pédagogiques Régionaux.* Circulaire 12 Juin 1952, Paris.

7. Aubert, G. La formation des maitres de l'enseignement secondaire. *Bulletin de la Societé Francaise de Physique.* no. 19, Janvier 1975, p. 22–23.

8. Walker, G.R. Combined Science-with-education Degrees. *Education in Science.* no. 54, September 1973, p. 21.

9. See for instance: Hamburger, E.W. Physics teaching in Brazil. In: *Survey of literature on physics education.* Edinburgh. International Conference on physics education. 1975.

10. Little, R.N. Pre-service of physics teachers: technical education. In: Brown, S.C., Kedves, F.J., Wenham, E.J. (ed). *Teaching physics: An insoluble task?* p. 63. MIT Press, Cambridge, Mass. 1971. 261p.

11. Richmond, P.E. (ed). *New trends in integrated science teaching: education of teachers.* p. 40. UNESCO Press, 1974. Paris, p. 227.

12. Peirson, E.G. *Worcester College of Education. A professional Degree for Intending Teachers.* Ebenezer Baylis and Son Ltd., Worcester and London. 6p.

13. private communication from E.J. Wenham.

14. Rogers, E.M. *Improving physics education through the construction and Discussion of various types of tests.* UNESCO, Paris, 1972. (photographic reproduction of the original manuscript), 117p.

15. Brown, S.C., Kedves, F.M., Wenham, E.J. (ed). *Teaching physics: an insoluble task?* p. 46 and 79. MIT Press, Cambridge, Mass. 1971, 261p.

16. Department of Education and Science. *Teacher Education and Training.* A report by a Committee of Inquiry appointed by the Secretary of State for Education and Science, under the Chairmanship of Lord James of Rusholme. London Her Majesty's Stationery Office, 1972. p. 128.

17. Smith, I., Stoneman, C.F., and Walker, G.R. The preparation of graduate science teachers. Education or training? *The School Science Rev.* vol. 53, no. 182. September 1971, p. 208.

18. Page, R.L. Reformation or Revolution in Teacher Training. *Education in Science,* vol. VIII, no. 42, April 1971, p. 18.

19. Matta, K. and deSa, B. Remarks on the Standards of Secondary School Students in physics and mathematics in Libya. *Survey of Literature of physics education,* 1975.

20. Faure, E. (ed). *Learning to be.* p. 241. Unesco, Paris, 1972. 313p.

21. Cross, J.B. A new four-year university curriculum for future teachers of physics and chemistry in secondary schools. In: Brown, S.C., Kedves, F.J., and Wenham, E.J. (ed) *Teaching physics: an insoluble task?* p. 155, MIT Press, Cambridge, Mass. 1971, 261p.

22. Haber-Schaim, U. Pre-service education of physics chemistry teachers. *American Journal of Physics,* vol. 39. 1971. p. 721.

23. E.D.C. Physical Science Group. *College Introductory Physical Science.* Prentice-Hall, Inc. New York, 1969.

24. Balasubramaniam, E. and Brazier, I.M. Problems of teaching physics concepts to New Guinea students. In: Hecht, K. and Blänsdorf, K. *Implementation of Curricula in Science Education.* p. 100. Verlag Dokumentation, Pullach/Munchen. 1974. p. 207.

25. Anonymous. Physics Education in the Arab States. In: *Survey of Literature on physics education.* Edinburgh International Conference on Physics Education. 1975.

26. See for instance: Oguntonade. *An Analysis of Nigerian Science Teachers' Opinions of an In-Service Course.* Paper presented to the first annual Conference of Sierra Leone Association of Science Teachers held in Freetown in 1974.

27. Brown, S.C. Report on the International Working Seminar on the Role of History of Physics in Physics Education. In: Brown, S.C., Kedves, F.J. and Wenham, E.J. (ed). *Teaching Physics: an insoluble task?* p. 83. MIT Press, Cambridge, Mass. 1971. 261p.

28. Tawney, D.A. The role of the Physics centres in initial and in-service training. In: Brown, S.C., Kedves, F.J., Wenham, E.J. (ed). *Teaching Physics: an insoluble task?* p. 129 and 132. MIT Press, Cambridge, Mass. 1971. 261p.

29. Japanese National Commission for Unesco. *Training of Science Teachers in Japan.* MEJ 80027, 1970.

30. Bronewshuk, S.G. In: Brown, S.C., Kedves, F.J., Wenham, E.J. (ed). *Teaching Physics: an insoluble task?* p. 115. MIT Press, Cambridge, Mass. 1971. 261p.

31. African Primary Science Programme. *In-service training of teachers.* P.O.B. M188. Accra, Ghana. 1971.

32. Reay, J. *Integrated Science and Teacher Education.* (ISTE). Caribbean Science Educators Workshop. 1973. School of Education, University of the West Indies, St. Augustine, Trinidad.

33. Private communications and the McGraw-Hill advertising leaflet, 1974.

34. Perlberg, A. Educational technology in the Professional Training of Science Teachers. In: *New Trends in the utilisation of Educational Technology for Science Education.* p. 235. Unesco Press, Paris, 1974. 257p.

35. Baez, A.V. Evolution of a Concentrated, Media-Activated Physics Course. *American Journal of Physics,* vol. 41, Nov. 1973.

36. Woolnough, B.E. The place of technology in schools. In: *The School Science Review,* vol. 56, no. 196, March 1975.

37. D'Aeth, R., Brown, F.T. The professional education of science teachers for secondary schools. In: *The School Science Review.* no. 51, no. 176. March. 1970.

38. During the ICPE Conference (1975) we discovered that such a Directory exists already, and has been provided by the ICASE. Interested persons may ask for "Directory of Science Teachers Associations World-wide". Mr. B.E. Atwood, A.S.E., College Lane, Hatfield, U.K.

15 Physics for technical education and technological literacy

This chapter consists primarily of the paper written by N.H. Frank, modified slightly by the working group at the Edinburgh Conference, which was responsible for the recommendations in the final section. The chapter begins by considering the several purposes of teaching physics, with particular reference to the supporting role of physics in technical education. After comment on traditional physics courses, the need for experimental work to focus on real systems and processes is considered, proposals are made for restructuring physics teaching around general principles that make physics cohere. Examples are given showing the adaptability of such a scheme to a multiplicity of student interests and goals. Discussion follows on the outcome of current technical physics programmes, focussing on how one might proceed towards the creation of a learning pattern to support the attainment of technological literacy, how to provide both qualitative insight and an appropriate quantitative base for adequate understanding of technological devices and processes encountered in the daily life of society.

15.1 INTRODUCTION

Physics is usually taught either as part of pre-professional education, as part of general education or in support of occupational goals other than that of becoming a professional physicist. Despite the quite different requirements of these categories, the widespread and continuing efforts to improve and make more effective the teaching of physics have mostly followed the same general pattern, largely independent of the several purposes of the foregoing categories. To be sure, there have been attempts to introduce material and methodology reflecting the special concerns of each, but the structure of physics courses has remained relatively static.

Part of the occupational goals of the third category is the specific purpose of achieving technical competence to service, maintain and assist in the production of technological devices. Many of the specific technical occupations, especially those in industrial and engineering technology, involve coping with materials, processes and systems that are heavily dependent on what is euphemistically called applied physics.

Since these areas of technology are growing in complexity and sophistication, the need for a good grounding in science, mathematics and communications becomes increasingly important in technical curricula. The speed with which specific skills are having to be replaced by new ones to accomplish more effectively the same general technological purposes emphasises the requirement for a solid and useful knowledge base. Without it there is little chance of even a skillful technician adapting successfully to new skill requirements without painful retraining, let alone moving upward in his chosen area.

15.2 TECHNICAL EDUCATION AND PHYSICS

Although the need for science (especially physics) and mathematics has long been recognised in technical education and although most technical curricula include courses in physics and mathematics, there is general agreement that these subjects fail dismally to accomplish what is expected of them. The technical courses lying at the heart of the curriculum generally fail to rely on what has been learned in the physics course. It is not uncommon to find electricity and magnetism excluded from the physics course and taught by staff of the electrical or electronic technology departments.

Because of this plight of physics in technical education, a national conference of physics teachers in post-secondary technical institutes and community colleges was held in the United States in May 1969. It aimed at planning a new and hopefully more effective pattern of teaching physics [1]. It was agreed that experimental experience would be more suitable for technical students than text-book centred learning, and that this experimental experience should occur in a modular format. Each module should be centred on the operation or performance of a real device or system, preferably one familiar to the student, and should occupy the students for some two to three weeks. The availability of a sizeable number of such modules, some thirty to forty, broadly conceived, would then enable schools with different clienteles, levels of aspiration and a variety of student backgrounds and teacher capabilities to synthesize physics courses best suited to their individual needs.

The American Institute of Physics set up a national steering committee to plan a programme for the production of such modules, and this committee and four production centres were subsequently funded by the National Science Foundation. The adoption of an experimental modular format for the teaching of physics raises a number of questions. These include the following.

1. Should the experimental experience be deployed primarily to illustrate physical principles or should the underlying physics emerge from this experience?
2. Should such an experimentally centred course be sequentially structured?
3. How extensive in scope and time should a module be?
4. Should the physics laboratory be separate from technical laboratories?
5. Should the experimental processes and devices be essentially technical in nature?
6. How should textbooks be used in conjunction with an experimental module? Do we need new software to support the hardware?
7. Since a broad spectrum (both with respect to level and variety) of experimental and written teaching materials is called for, should the individual modules that serve as resource material be essentially self-contained?
8. Can the requisite equipment be made sufficiently cheap, available and viable so that schools can afford it?

No firm answers to these and other questions were given but rather it was hoped that they would emerge from the production and field trials. The results of this effort to date will be discussed later in this chapter.

15.3 HOW PHYSICS IS USUALLY TAUGHT

The foregoing pattern of a laboratory-centred investigative mode of teaching physics has implications that reach far beyond the relatively limited purposes of technical education. The criterion for success lies in the extent to which physics supports and strengthens the main thrust of a technical education programme, whatever area of technology is involved. The role that physics can play in providing meaningful support for educational missions or targets other than that of learning physics for its own sake makes it desirable to examine how well the more traditional patterns of teaching physics are adapted to these broader purposes.

The format for physics teaching has, by and large, been created by professional physicists and reflects their interest in and dedication to the science for its own sake. Generally taught as a separate course or sequence of courses within a curriculum that itself is preponderately a collection of disciplines, only too often it tends to become a relatively self-contained operation, coupling loosely at best with other areas of man's knowledge and even more loosely, if at all, with more general human purposes. With good reason the presentation reflects much of the historical development of the science, but for supportive purposes this turns out to be a somewhat mixed blessing. The structure is largely topical, focussing largely on presentations of mechanics, electromagnetism, optics, thermal physics, atomic physics, etc. There has been, however, a trend to depart from this both at secondary school and at college and university levels. Generally physics, along with other sciences, is taught as a transfer of information and ideas, more often than not as a largely deductive exercise. Textbooks occupy the centre of the stage; laboratory and experimental investigation are at best cast in roles that support the textbook. The advantages of this pattern are self-evident. A well written textbook is an excellent vehicle for displaying the cohesive character of the great principles and generalizations that lie at the heart of scientific knowledge and understanding. But there are problems. These derive from the multiplicity of backgrounds, interests, aspirations and learning styles of different students. In particular, most people find it more comfortable to proceed from practical, concrete experience to the domain of conceptual and abstract ideas than to follow the opposite road. The latter characterizes much of the teaching of physics. It is patently evident in the case of technical students who are instinctively "hand-minded" rather than "symbol-minded". This indicates that concentrating initially on technical physics as it supports a well-defined, unambiguous educational mission is a good way of uncovering the strengths and limitations of a laboratory-centred investigative approach to the learning of physics.

It is interesting to contrast the way in which physicists work with the way they teach. The working physicist is overwhelmingly problem- and mission-oriented. Perhaps his or her most cogent resources lie in the unity and coherence of physics. The physicist is inordinately proud of the way in which a relatively few pervasive principles and general methods of attack on problems have led to understanding of a broad range of phenomena, from cosmological to nuclear physics. But the largely topical presentation of physics too often prevents the student from obtaining adequate insight into these central themes of physics. Tò illustrate this, consider the widespread phenomenon of resonance which can occur in almost all physical phenomena. When studying resonance in simple electrical circuits (such as a series R, L, C circuit) the phenomenon is generally illustrated by plotting current and phase angle between voltage and current as functions of the applied frequency, yielding the familiar peaked resonance curve for current and the corresponding monotonic curve for phase angle. But when studying optical resonance, the representation is that of the frequency dependence of the real and imaginary parts of the complex index of refraction. That the latter is equivalent, despite the marked difference in the curve shape, to the simple electrical case is by no means evident to the student. It is relatively rare to find electrical resonance described in physics texts in terms of the in-phase and out-of-phase components of the current relative to the impressed voltage (or equivalently the conductance and susceptance) as functions of frequency. When this is done, the identical nature of electrical and optical resonance becomes evident.

15.4 LABORATORY-CENTRED PHYSICS

As previously indicated, the propensity of most people to move instinctively from the specific to the general suggests strongly that there is a real need for an alternative to the conventional format in the form of a laboratory-centred, investigative structure for learning physics. This does not mean that the traditional physics experiments will do the job effectively. Such experiments are usually designed to serve as vehicles that will reveal to students the "validity" and use of the physical principles and concepts stated in textbooks. Hence it is understandable that most of such laboratory equipment is over-designed. The prevailing idea that there should be a "successful" outcome of a physics laboratory experiment has only too often resulted in limiting sharply, for the student, the invaluable insights acquired by the designer in "debugging" a piece of equipment to insure the desired behaviour. This over-idealization of experimental investigation has its counterpart in textbook problems so highly idealized that the gap between the situations so analyzed and what goes on in real processes becomes very large indeed. Having been drilled thoroughly in problems of projectile motion in a vacuum, for example, it is revealing to observe the uncertainty (or at times consternation) that occurs when a student is asked whether a ball thrown vertically in the atmosphere takes longer to rise or fall. Laboratory experience would be greatly enriched by involving the student with manageably complex operations, and the design of this type of laboratory is challenging indeed. Within it a student would have ample opportunity for decision-making, especially if malfunctions are exploited as learning aids, something not generally available within the conventional physics course.

Experience with technical physics provides indicators as to how to develop supportive physics, where the educational goal may go far beyond the sharp but relatively circumscribed purposes of technical education. In any event the experimental work should exploit those real systems, processes and materials as units for learning that are central to the goal that is to be supported. Of course support is generally required from areas of knowledge other than physics, but if the goal is largely technological, physics does play a key role.

Even in general education, where Gerald Holton has so eloquently urged that the discipline of physics abandons its relative isolation and be constructively coupled to other disciplines in such a curriculum, it would be desirable to couple physics tightly (albeit in a support role) to systems, processes and devices that pervade everyday life. The Holton proposal resembles a many-body system with internal interactions, whereas the latter suggestion is more like a central field problem in which the supporting disciplines are coupled primarily to a central mission and hence only indirectly one to another. In highly industrialized countries the world is largely man-made and the daily life of people is heavily dependent on technology, and in the developing countries this dependence on technological devices steadily grows. Consequently there is much to be said for exploiting familiar technological devices and operating systems as vehicles for learning. In contrast to, but closely related to the goals of technical education that prepare a person to maintain, service and partake in the production of technological devices, the primary aim here would be the attainment of *technological literacy*. Physics can and should supply much of the foundation for the attainment of such literacy which must be of sufficient depth to enable people to make informed judgements about technology and its impact on the life of a nation.

As might be expected, the physics underlying the operation of technological devices and systems in no way resembles the traditional topical format of teaching physics. Boundary lines between standard physics topics cease to be sharp and the resulting topical amalgamation is exemplified by the appearance of terminology such as electro-mechanical, electro-optical, magneto-hydrodynamic, etc. This suggests that, when employed primarily in a supportive mode, physics teaching should be structured around those general pervasive principles and methods that make physics cohere, drawing on a variety of topical areas to exemplify, clarify and gain insight into the power of these general themes. In this way individual contributions can readily be adapted to a multiplicity of student interests and goals.

Examples of such general themes are forces and motion, conservation laws, flow processes both steady state and transient, oscillations and resonance, coupled systems and waves (stressing the commonality of the kinematics of wavemotion and the individuality of specific kinds of scalar and vector waves), scalar and vector fields, microscopic modelling of macroscopic systems, passive and active amplifiers, stability and feedback, statistical fluctuations and noise in physical systems. One may question whether this suggestion embodies too much of classical physics that has disappeared from today's presentation of physics and perhaps taints the purity of physics by the inclusion of engineering-related ideas. It would seem beneficial to include these for two reasons; it would provide a strong line for an experimental entry into physics that would be a distinct alternative to traditional formats and would do much to break down the unwanted isolation of too many physics courses from real, albeit man-made, devices and operations.

There is a real requirement for the generation of text material of the general character suggested in the preceding to support a laboratory-centred introduction to physics. Among the reasons for this is the large amount of time that laboratory or experimental work consumes. Laboratory experience, whether cast in the modular format of the technical physics programme or not, must be broadly conceived so as to deal with a general principle or method. If successful, such understanding as is derived from this can then be transferred with little effort to similar but not necessarily identical situations in other topical areas of physics. If modules are to be relatively self-contained, it will be necessary to have a sizeable amount of textual material contained in them. The question remains, however, whether what is derived from n modules will end up as n distinct learning segments. It may well be that text material of the sort suggested above would supply the 'mortar' necessary to transform n isolated 'bricks' into a unified structure. It is of interest to note here that there is an inherent difference between a textbook and a piece of equipment as a learning vehicle. The level at which a textbook can function well is determined by the level and style in which the author casts his material. This is especially true of the mathematical level employed. A piece of equipment, on the other hand, is a far more versatile learning aid. Depending on the kind of question one asks of it, it can function usefully at practically any level of sophistication. The text material in the technical physics modules has to be fashioned to communicate with students who are generally neither verbally nor mathematically adept. Hence, heavy reliance on pictorial and graphical presentation is prevalent and this helps to make tangible much of what the written material attempts to communicate.

15.5 TECHNICAL EDUCATION AND TECHNOLOGICAL LITERACY

The discussion of the principal outcome of the technical physics programme to which reference was made earlier in this chapter has been deferred to this point in order to indicate how these results might be adapted and modified to teach physics for technological literacy. The modules that have been produced by the four production centres have varied considerably in emphasis and style, reflecting the judgements of the individual working teams. It is of interest to note that concern with adequate 'coverage' of physics has ranged from coverage of topics to that of the dominant principles and methodology of physics. Here the discussion will focus on the work done at the Technical Education Research Center at Cambridge, Massachusetts, U.S.A., an effort with which the author was intimately involved.

Each module was built around a dominant theme such as that of heat dissipation and ways in which such dissipation may be enhanced or controlled to insure proper operating temperature ranges for the device under study. Clearly this is of universal concern whether one is interested in physical or living systems, and as such is germane to education for technological literacy as well as to technical education. The structure of a module derived from the conviction that the future technician must not only acquire a qualitative understanding of the physics involved in the device or devices employed. He or she must be able to make reliable quantitative measurements with suitable instruments, to display the data acquired appropriately and to be led to an understanding of how these data indicate the character of the physical laws underlying the phenomena under investigation.

The general strategy for building a module is then somewhat as follows. First a general, qualitative presentation of what will be going on in the module, introducing requisite physical concepts without concern for precise definition at this stage. For example, it is possible to introduce the student to the concept of energy along these lines, starting with the ideas of mechanical energy (first energy of motion and then potential energy of configuration) then extending the idea of potential energy to the broader concept of internal energy of a system including some mention of the special character of thermal energy. Then follows a set of relatively rigidly prescribed experiments with the instrumentation needed to turn the qualitative ideas into quantitative ones, including the calibration of such instruments.

The second part of the module is designed to have the student make such measurements on the device in operation as are needed to disclose what is going on quantitatively and then display the results of his measurements graphically. The use of graphs to get numerical answers to questions by its very nature avoids the discouraging task of getting students to pay proper attention to significant figures in answers to problems. The inevitable uncertainties in the measurements themselves insure that not only the use but also the desirability of approximation methods become evident. Furthermore, it is not difficult to get the student to grasp the essence of the exponential decay of temperature as something cools. The plot of his data *is* the portrayal of a decreasing exponential and from the graph it can be roughly established that the cooling rate at any time is proportional to the temperature at that instant. All without an equation! At this point, for those students who are not repelled by algebraic symbolism, and not before, one should pull together the quantitative results into an analytic formulation. These are general guidelines and while it is at times not feasible to adhere strictly to the sequence proposed, the general pattern can be followed and finds favour with the students. Teachers, on the other hand, are tempted to be critical and their criticism is revealing. The general complaint, after working through a module, is that it is not 'theoretical' enough – an indication of how easy it is to misidentify theoretical physics as the exercise of obtaining analytical solutions to physics problems.

The third and final part of a typical module then takes the student into measurements and discussions that show (or are intended to show) how what has been learned in the first two parts can be used to investigate and understand a broader range of phenomena than those which comprise the earlier experience. In this third part, the student is given considerable freedom in deciding how to proceed. It is envisaged that each third of such a module would engage a student for about a week, and this scheme has the advantage that much can be learned by working with only the first two parts or even just the first part of a module.

It is significant that the physics which flows out of the operation of a technical device or system is generally so extensive and varied that considerable self-restraint must be exercised by the author of a module exploiting the device in order to keep the module within manageable bounds. A typical example occurs when one employs a spectrophotometer as the vehicle about which one or more modules are constructed. Using a two-dimensional optical bench with the optical elements held magnetically (templates can be used to save time and avoid frustration), not only does one become immersed in geometrical and physical optics, but it also becomes possible to study the spectra of various sources of light (atomic physics), to study the physics of various photodetectors (solid state physics) and finally, to investigate the interaction of light with matter as it passes through the sample to be analyzed. Thus one is confronted by a wealth of physical phenomena, far too extensive for even a few modules.

Much of what has been presented above as the general investigative pattern for learning physics in technical education could presumably be adapted to general education aimed at the attainment of technological literacy. To be sure, the very necessary emphasis on manipulative skills for technicians would be considerably reduced and the choice of suitable experimental vehicles for learning would be made not in terms of potential job opportunities but rather in terms of the dependence of the population at large on technological devices and processes, especially in its daily life. Thus the general state of technological advancement in a given nation would be reflected in the way at least part of its educational programme takes shape and the latter could well evolve concurrently (or with minimum time lag) with national technological growth. The quantitative part of this sort of physics presentation might well be about the same as for future technicians, perhaps with somewhat more emphasis on order of magnitude estimates and calculations.

It should be emphasized that the modular format adopted by the Technical Physics Programme is by no means sacrosanct. Any structure based on experimental investigative learning with the help of real devices and processes could presumably serve as well as a modular structure. The structure should be chosen on the basis of how well it works in practice. But in any case the instrumentation needed to make appropriate measurements occupies a central position in any genuine attempt to produce a solid intellectual base for the understanding of technology. If a pattern other than modular is employed, an 'instrumented' laboratory might well serve as a major resource. Man's progress in understanding the physical world has been critically dependent on his ability to invent and devise improved instrumentation to investigate it, that is, to extend his unaided senses. Not only must a measureable physical quantity be detected, but the information thus disclosed must be processed and displayed in a manner best suited for the purposes at hand, whether the latter are to serve diagnostic ends, to control by means of feedback, or to produce as a means of moving forward towards further stages in attaining educational goals.

In the modules for technical physics described above, advantage has been taken of modern electronic technology, using predominantly compact, versatile and relatively cheap integrated circuits for signal processing. Transducers are utilized to convert the detected physical quantities into electrical signals for appropriate processing. The advantages of multiple use of the same basic equipment are evident and a number of suitable components employing integrated circuits might well serve as the basic ingredients for an 'instrumented' laboratory. The work of Doris R. Entwistle and W.H. Huggins at John Hopkins University [2] has shown clearly how rich this process can be.

In summary, the suggested format of investigative learning of physics takes one from the specific to the general rather than from abstraction to application. It is proposed that the former lead primarily toward the acquisition of understanding and insight into those broad pervasive principles and methods that make physics cohere, pursuing selected topical areas in depth to clarify and exemplify the power and the utility of these principles. The latter only too often overemphasises mathematical deduction to the detriment of physical insight and, for feasibility reasons, applications are made to idealized processes. Real processes are extraordinarily complex and more often than not require a considerable mix of basic knowledge and empiricism to deal with them effectively. On the other hand, as an alternative to traditional patterns of teaching physics, the proposed structure is open ended and has the potential for moving a student as far as his individual capabilities allow towards the attainment of technical proficiency or technological literacy.

15.6 RECOMMENDATIONS

The working group at the Edinburgh conference were unanimously of the opinion that the basic notion of an experimental investigative pattern of learning physics showed high potential for effective utilization in primary, secondary and tertiary education fields as well as in technical educational schemes.

Confirmation of this judgement arose independently from several other sources in the conference. This was evident from the address of Sir Hermann Bondi and that of Professor H.B.G. Casimir, from other chapters in this volume, in particular Chapter 3 on 'New Approaches to Teaching and Learning in Universities', and from the discussions of several working groups.

The working group recommended strongly that further study be made of the development and adaptation of these ideas and that funds be sought to finance (1) collation of papers relating to research, development and utilization of these ideas for a variety of educational purposes, (2) a conference to bring together participants for the purpose of devising appropriate strategies for the optimal deployment of basic patterns of investigative laboratory-based learning to best serve their individual educational goals.

15.7 REFERENCES

1. Aldridge, Bill G. "Physics for Two-Year Technical Curricula". *The Physics Teacher,* vol. 8, no. 6 (Sept. 1970), pp. 302 ff.
2. Entwistle, D.R. and Huggins, W.H. "Simulated Environments in Higher Education". *The School Review,* vol. 75, no. 4. University of Chicago Press.
3. diLavore, Philip. "Physics of Technology – A Report of the Tech Physics Project". *The Physics Teacher,* no. 11, p. 473, 1973.
4. Fibel, Lewis R. "Survey of Technical Physics". *The Physics Teacher,* no. 11, p. 491, 1973.

16 Physics and recent trends in education

The discussion of this issue at the Edinburgh Conference was based upon a paper prepared by E.W. Hamburger, which emphasised some aspects of the 1972 report of the International Commission on Education entitled 'Learning to be'. Comments and recommendations of the working group are interspersed in the text of the basic paper.

16.1 INTRODUCTION

Physics learning and teaching is an activity which interacts with many other social activities and institutions and with many fields of knowledge. In this chapter we will concentrate on the influence of certain general ideas about education and science on physics teaching and learning.

Education, and science education in particular, is believed to promote aims such as: democracy, development, equality, tolerance, creativity, independent critical thinking, scientific attitude, demystification of science, and so on. The type of question we will be concerned with is: does physics education as practised today further these aims? Can it further them and is it at all pertinent to them?

Of course physics is a very small part of education and one may argue that even if physics education were perfect, leading to the very best educational aims, the overall effect on society would still be negligible. This is an unduly pessimistic attitude. Social changes can start gradually. Physics teachers have already in the past introduced some appreciable changes in education, such as the big curriculum development projects of the last twenty years (the pros and cons of which will be discussed in other chapters). Furthermore such questions are important for us as physics teachers because they tell us how our professional activity is contributing to society as a whole.

The theme of this chapter was originally inspired by the Unesco publication *Learning to be* [1] and most of the issues raised are discussed therein. The issues mostly refer to education as a whole and have so far been discussed from a general point of view. Here we try to make the discussion specific to one field of knowledge, physics.

16.2 PRIVILEGE

The word 'education' describes the means which a society uses to perpetuate itself from one generation to the next. It seeks to transmit to coming generations the knowledge, the experience and the value system of the present one. The function of teaching can be considered 'the reproductive function of a society' and 'genetically speaking the primary quality of a reproductive system is to reproduce its type as exactly and as faithfully as possible' [2]. Education is therefore by its very nature conservative [3].

On the other hand, throughout history the educational system has always been intimately linked to the hierarchical structure of society, and it reflects the distribution of power and the principles of social control in that society [4].

Thus often the school system acts primarily as a sieve, starting in the elementary classes and operating through successive stages of filtration in order to select the future elite. The determining factor is the principle of selection, based on criteria determined by the existing elite, which continuously makes the restrictions more stringent [5].

Physics nowadays occupies an important place in this process of selection. In Europe in past centuries, Latin was the main requisite. Today the examination at the end of secondary school or the university entrance examination usually requires considerable knowledge of mathematics, physics and other sciences. The tendency seems to be that no citizen without this knowledge will have access to a university and therefore to higher positions in society.

In many countries, only people having a university degree have a good standard of living. Salaries of people who do not have a diploma are very low. However, the degree requirement does not reflect an actual need for the high-salary position: these positions often do not require special abilities, at least special academic abilities. Thus the important thing becomes the diploma, while the abilities it is supposed to guarantee are unimportant. Such a situation, in which education serves primarily to assure certain privileges for some people, produces specific effects in the educational systems. For example it encourages practices such as cheating in examinations, forging of diplomas, founding of colleges of low academic quality where anyone can buy a diploma, etc. It also allows syllabuses to become irrelevant and enhances the importance of examinations.

The vested interests in education have tended to support this exaggerated value placed on diplomas from accredited institutions. The educational establishment comprises, as well as teachers and educational administrators, many businesses connected with education such as publishers, audiovisual material producers, school furniture factories, etc. These forces have pressed for a continuous expansion of the number of schools.

Some critics, such as Ivan Illich, feel that education today is so strongly influenced by the interests of this establishment that the only way to allow education to truly serve mankind is to 'de-institutionalize' it, to 'de-school' society [6]. Education would continue to exist but would no longer be a monopoly of schools or other institutions. Actually the school as a place where people get together to study and learn (and teach) is a very useful institution which will probably survive many social reforms. It would seem that the important point is not to abolish schools but to abolish the privileges pertaining to degrees.

If a university degree conferred no privileges, the whole structure of education would be affected. For it is these privileges that have been the main motivation leading people to study. Modern society is very technological and complex and needs a large number of highly trained technicians. The economic and military strength of a nation depends on the existence of this manpower, and this has been the reason why these people have been rewarded in the past. The abolition of privileges related to degrees would therefore have important political consequences. It affects the very essence of the rôle of education in society, and would not be possible without profound changes in other aspects of the social structure [7].

The attitude of students is determined in great part by the benefits which they expect from the diploma. Diminution of degree privileges would affect their attitude very much and would bring about changes in the teaching and learning of all subjects, including physics.

Issue 1: *Should (and can) privilege pertaining to degrees be reduced or abolished? How would this affect the teaching and learning of physics?*

Physics is one of the required subjects at the end of secondary school. Since it is a difficult subject it seems very useful as a means of selection of the elite. One may ask oneself whether today's requirement of physics will look as unimportant in future centuries as knowledge of Latin seems to us now. The argument in favour of physics seems quite reasonable: society today is so dependent on science and technology that a basic knowledge in these fields is indispensable to anyone destined to make important decisions. We have probably all used this argument on many occasions. However, what is the empirical evidence supporting it? It can also be argued that knowledge of science is not essential for intelligent decisions. Certainly in the past people who made decisions had very little knowledge of science.

Issue 2: *What knowledge of physics should be required at the end of secondary school?*

16.3 EXAMINATIONS AND GRADES

The teaching of physics at all levels is deeply influenced by the degree system. At each level, even at the post-graduate level, the studies lead to an examination. The examination becomes the major aim of the students. Textbooks accordingly are written with the idea of teaching for an examination. Often drilling in the solution of problems becomes the main activity in the courses. The teaching tends to be dogmatic: questioning of the theory becomes of minor interest, the important thing is to learn to give the 'right' answers to questions and problems of the type set in examinations. These are efficient methods if the aim is to pass examinations. However it is difficult to see any other utility in such activities.

Many teachers believe that the undesirable effects of examinations can be much reduced by proper wording of the questions set. However there are important aspects of examinations which do not depend at all on the questions. The most important is the social punishment (or threat thereof) inflicted on those who fail to pass. Perhaps one can make an analogy with McLuhans 'the medium is the message': the effect of an examination is in great part determined by the examination 'medium' quite independently of the content.

Assessment in some form is often a necessary part of the learning process itself. However, the social significance of the examination is often so important that its function in the learning process is impaired.

Issue 3: *How would we teach if there were no examinations of any kind? Or if the examinations had no effect on what the student was allowed to do later in life?*

Examinations seem necessary as conditions for granting a licence for the practice of certain professions – surgeons are often quoted as examples – in order to protect the public from incompetent practitioners. In reality such examinations often do more to guarantee the privileges of the professional group than to protect the public. The existence of the examinations is directly related to the existence of the privileges.

Most examinations today do not pertain to a real profession but to knowledge and abilities which some educational authority has considered important for some professions or for citizens in general. Examinations are thus thought of as 'mock-ups' of situations which the examinee will face in life and pretend to verify whether he will in fact be able to face that situation successfully. However actual examinations are far removed from 'real life' situations and refer exclusively to the academic world, closed upon itself.

Physics examinations, in particular, do not usually resemble any real situation which the examinee is likely to encounter in life. Physics is a 'pure' science; by definition only 'applied' science situations occur. Physics examinations usually test whether the candidate knows the meanings of certain key words and makes certain abstract operations with them. As far as the general intellectual abilities being tested are concerned, the subject of the examination might well be Latin.

Some professions seem to be relatively free from the scourge of examinations. Football players, for example, are not selected by examinations but on the basis of how well they play. This does not mean that an intensive educational (usually called training) programme is not necessary to make a great player. However his competence is determined by a more direct test than school examinations.

Actually the competition for the best places within a profession is always made by more direct measures of success than examinations. If one tries to determine the correlation between success in professional activities, on the one hand, and results and grades in schools, on the other one usually finds that the correlation, if it exists at all, is extremely small (this has been shown in a number of studies, particularly with respect to university grades; see the review by D.P. Hoyt [8]). The lack of correlation between university grades and subsequent professional success shows how arbitrary the selective process of the educational system is. Particularly questionable are the large selection examinations at the entrance to the university.

Issue 4: *To what extent would it be desirable and possible to abolish examinations, and physics examinations in particular?*

16.4 LEVELS AND PREREQUISITES

Another related characteristic of the education structure is the division of all knowledge into levels. It is as if God had created nature in three parts: secondary school, undergraduate and post-graduate levels [9]. Only the deepest level makes sense from a scientific point of view. This mania has principally affected university courses. Since the dissemination of post-graduate studies in the last forty years, undergraduate courses have in large measure become a strange no-man's-land between the school introduction to a subject and the post-graduate course, which really comes to grips with the subject. For example, introductory physics courses for scientists or engineers are usually very unsatisfying for both students and teachers, because they always stop short of anything real, difficult or profound. One somehow has the feeling that this is some artificial food, dehydrated science or the like, which does not get reconstituted [10].

The concept of 'level' also sometimes causes teachers to make a subject unnecessarily difficult. It is felt that to explain it in detail, so as to make it easy, is 'spoon-feeding' and would lower the level of the course. Physics courses are thus made deliberately difficult, so as to act like a filter, just like the examination.

Issue 5: *Should the concept of 'level' of a course be revised? How many levels should one assume?*

The myth of prerequisites is another feature of degree-dominated education. Very often educators require prerequisites that are not really necessary, but only customary. In this way it becomes more lengthy and difficult for someone to acquire certain knowledge or abilities. Moreover, we have all had the experience that in physics much learning is done backwards, i.e. a certain subject is only well understood after other more advanced subjects have been learnt.

A related point, raised in *Learning to be*, is the predominance of the written word as a means of communication [11]. Physics is only taught to literate people, literacy is considered a prerequisite. It may be that it is dispensable, although some graphic representation is certainly very useful because of the abstract nature of the subject: diagrams of vectors, Feynman diagrams, and the like. However the accompanying narration need not be written; it could, for example, be oral, or multimedia methods could be used. Then it would be much easier for barely literate people to learn physics. Actually, the custom whereby all scientific work be reported in writing, while undoubtedly important in the history of science, also represents an impoverishment of scientific communication. In effect, scientific discoveries are much richer and much more complex than can be reproduced in a (necessarily linear) written narration.

Issue 6: *Should physics teaching material demand fewer prerequisites?*

Issue 7: *Should methods of physics teaching be developed which rely less on the written word and more on oral communication?*

16.4.1 Working Group Comments

Sections 16.2, 16.3 and 16.4 maintain strongly that examinations and other selection procedures tend to perpetuate existing society and the formation of an elite. The working group at the Edinburgh conference made the following comments.

(a) Examinations were originally intended as a democratic procedure to allow everyone of ability equal access to higher education and the professions irrespective of wealth. Examinations still remain more democratic than some alternatives.

(b) Examinations remain necessary for certain competence controls (for example, in medicine or law) and for selection. Selection will always be needed when desire exceeds the places available, but selection procedures should and do vary. It was thought that existing examinations, especially in the early stages, did perhaps make excessive demands on literary ability.

(c) It was felt that examinations should be locally based. It is not desirable that educators in one country should examine by correspondence students in another.

(d) It was agreed that efforts should be continued to make examinations test the acquisition of skills, attitudes and the ability to learn rather than the mere acquisition of factual knowledge.

(e) Continued education throughout life may reduce the undesirable effects of selection by giving people later opportunities for participation in organized education.

16.5 DEMOCRACY

Learning to be stresses that education should strengthen and develop democracy in its broadest sense [12]. However some critics feel that the educational structure, as it exists today, is intrinsically a tool of oppression. Thus Paulo Freire [13] calls it 'education for domestication', in contrast to 'education for liberation' which, 'utopic, prophetic and hopeful', is 'cultural action for freedom and therefore an act of knowing and not of memorisation only' [13].

Education for domestication is transmission of knowledge from a teacher who knows to a learner who does not, and is compared to a deposit system, in which the teacher deposits the knowledge in a previously empty container, the learner [14]. The learner is passive, has no voice in the choice of content and does not act on the knowledge received, since it is far removed from his daily life experience. Reality is given and is not to be acted on. John Dewey called this kind of education 'a dead thing'. Thus in many underdeveloped countries all school materials are chosen to fit the values of a minority of the population (which has a high standard of living) and are inappropriate for the majority. For example, in the Brazilian northeast, a physics teacher had great difficulty in convincing his pupils that man had already reached the Moon. Would they be able to grasp abstract ideas such as gravitational fields, conservation laws and the like? Even if they did, what relevance would it have for their lives?

In 'education for liberation', on the other hand, the teacher must also be learner and the learner must also be teacher, and the knowledge which they attain together is not given a priori from some stratified store of knowledge, but is discovered together in a quest motivated by real problems faced by the community. This education is seen as a way for the teacher-learner pair to act to change reality, while education for domestication seeks to adapt the learner to the status quo.

The ideas of Paulo Freire developed from his experience with literacy campaigns in Latin America. Here the traditional method had been to teach reading and writing to poor adults, usually by rote learning. The conceptual framework of the teaching was that of the ruling classes, to which the teachers (or at least the campaign organizers) belonged. It is easier to understand his ideas in this context than in respect of physics teaching, where teachers and learners mostly belong to the same social class. However, the ideas seem to apply also in the general educational context.

Most teaching of physics in the world is of a type where the teacher selects a topic, usually abstract, which he knows well and the students do not know, and talks about it or has the students work on it. Only at the highest level, in post-graduate studies [9] does education sometimes become a partnership. An eminent nuclear physicist once said that if a student for the Ph.D. degree "is at all worth his salt, you learn as much or more from him as he does from you". This is true education with equality and in this sense democratic [15].

At the lower levels, secondary and university undergraduate, it is much more difficult to teach physics in this way. How many teachers have the courage and the possibility of tackling real problems, whose solution they themselves may not know, with their students? Or is it really necessary to wade through many years of transmission of dead (or almost dead) knowledge before tackling a real problem?

One point which should be stressed is that physics is usually taught rather late in life, after age 16, to young adults whose fundamental brain capability is already fully developed. There seem to be no intellectual limitations to what they can do. For younger children such limitations must be taken into account. The previous discussion is however fully valid for late secondary and university education.

Issue 8: *Is it possible, and is it desirable, to teach physics at all levels as a partnership such that the topics are chosen freely by teacher and students? Can these topics be related to actual problems of the community?*

16.6 SCIENTIFIC METHOD AND THE MYSTIFICATION OF SCIENCE

One of the aims of science teaching (and of physics teaching in particular) is to show students what the 'scientific method' and the 'scientific attitude' are. It is not easy to define these terms, but presumably they are the methods used by, and the attitudes of, scientists. Analysis of scientific activity is a field of the philosophy and sociology of science which has been the cause of much controversy during the last decade [16]. The model of Popper, according to which scientists are permanently trying to test their theories by doing new experiments and are ready to scrap a theory as soon as it disagrees with experiment, has been shown to be oversimplified. Kuhn and others have argued that most theories are confronted with apparently contradicting data all the time and yet are not abandoned as long as it seems possible that new data will support the theories. A major theory will only be abandoned by the scientific community after a scientific revolution. Most scientists during most of the time do what Kuhn calls 'normal science', i.e. they endeavour to adapt the existing theoretical framework ('paradigm' in Kuhn's terminology) to account for more data. Only on certain occasions do revolutions occur in which the paradigm is replaced by a new one. The main examples of such revolutions in physics are the Copernican revolution in the sixteenth century and the rise of the theories of relativity and of quanta in our century. The experimental data on scientific revolutions are thus still rather scarce. It is possible that, under very different social structures, scientific activity would proceed in a different manner; the history recorded so far refers only to the social structures extant in Europe during the last 500 years.

Science teaching overwhelmingly emphasizes *normal science*. The student is to learn what is believed within the accepted paradigm, and to learn to apply this paradigm in situations in which it has already been applied. Examinations always refer to problems which have already been solved. The aim of education, principally at the post-graduate level where scientists are trained, is to train the student in applying the extant paradigm, allowing only for minor extensions and generalizations here and there. Paradigms which have been accepted in the past and are now no longer accepted are taught as being 'wrong' or not taught at all.

It is interesting to quote from Kuhn's book [17] on this subject: "the depreciation of historical fact is deeply, and probably functionally, ingrained in the ideology of the scientific profession" while scientific education is typically "narrow and rigid . . . . more so than any other except perhaps orthodox theology".

When science as we know it was born, at the time of Kepler and Galileo, it had to fight against religious and academic dogma. At that time it seemed that science was the antithesis of dogma. Now the accusation that science is the new dogma, scientists the new priests, must be faced with the realisation that it contains some truth.

Scientists and science teachers often contribute toward the mystification of science. Science is shown as an extremely difficult activity, out of reach of the majority of mankind. Scientists are heroes to be worshipped. Scientific predictions are beyond dispute, except if other scientists dispute them with very sophisticated arguments.

Following Kuhn's work, there has recently been a greater preoccupation with the role of the history and philosophy and maybe even the sociology of science in science teaching. In physics, the Harvard Project is an outstanding example. Whereas, previously, scientific results were taught without trying to connect them to other things happening in the society of the time (history of science in science courses used to be limited to short biographical sketches of the type 'born in 1833, son of a tailor') the new approach tries to place scientific discoveries in the cultural setting in which they were made.

Probably this is a healthy tendency and should be accompanied by a very critical attitude concerning the rôle of science in society, avoiding an attempt at glorification. The demystification of science is an important aim of science education [18].

What other consequences for science education do ideas like those of Kuhn imply for science education? Are we satisfied to teach only normal science, to indoctrinate students with puzzle-solving methods applicable only for the small steps in science, and totally inadequate in the more creative, revolutionary phases? If not, how should we teach in order to deal with the major steps? This is probably an important point to try to answer in the future. Is the rigid narrow education described by Kuhn necessary to make good scientists?

Issue 9: *Does science education as it exists today contribute to the mystification of science? If so, how could this be avoided? Should we continue to indoctrinate students with normal science or should science education become more open, less dogmatic? What might the consequence of such a change be?*

16.6.1 Working Group Comments

The above two sections argue that if education is to strengthen democracy and encourage the liberation of the oppressed, then it should be a partnership between the teacher and the student in which they are together learning and teaching. They call attention to the fact that science is often (mainly) taught as dogma and science education consists only in training students to know and apply the accepted norm. The working group at the Edinburgh conference made the following comments.

(a) They recognised difficulties in the desirable move towards a teacher-student partnership in learning. It may be necessary to introduce more liberal methods of physics education gradually, in circumstances where relationships in family and society, or dogmatic teaching in other disciplines, are at variance with these methods. It was suggested that the relationship of research student and supervisor might illuminate that of pupil-teacher.

(b) The degree of freedom of choice was considered both in respect of the content of courses and in the approach used. It was suggested that the inexperience of the student limited the freedom of choice that he might be given but that one should work to maximize freedom for teacher and student working together. None the less, both have a responsibility to society with regard to education and, equally, society has a right to some share in educational decisions. (An example was given of a case where the free choice of the student at university level had been found unsatisfactory because of the different attainment needed for subsequent work.)

(c) The group recognised a trend towards learner-centred pedagogy and individualized learning methods were discussed. Small group work appeared to avoid both the monologue of the teacher and the equivalent monologue of a programme, providing experience of interaction which is one of the features of developing science as well as of liberal education. The opinion was expressed that small heterogeneous groups work best as students learn from each other, but problems of assessment in the group situation do not yet seem to have been tackled adequately.

(d) It was suggested that human beings are perhaps naturally competitive and it was important to use this quality positively and to minimize its dangers and disadvantages.

(e) There was general support for a problem-solving approach as being closer to the real nature of science and more capable of adaption to the realities of the local context.

(f) In many countries teachers lack social status and adequate rewards. This is liable to reduce the effectiveness of the profession as a whole and of those individuals who become overworked, angry or bitter as a result. Teachers must strive for professional competence and expertise and should be given every help by the appropriate bodies; society must recognise the importance of the teacher's role in the educational process.

The working group at the conference agreed on the following recommendations:

(1) The trend towards learning partnership of teacher and student should be encouraged at all levels and in all countries even if change must come gradually. Even where the social context inhibits this development it should be encouraged in the effort to reduce dogmatic attitudes.

(2) Development that supports this approach should be encouraged. A wide variety of educational activities should be available to teacher and student in order to provide the most effective learning situation at any particular moments.

(3) Educational developments should work toward maximizing the freedom of teacher and student within a context of social responsibility.

(4) Educational methods should give scope to the creativity, critical judgement and independence of the individual, while at the same time developing his awareness of his role in society and his ability to live and work as a member of a group. These aims should take precedence over any desire to preserve the content of the syllabus.

16.7 DEVELOPMENT

It is usual today to classify nations as developed, developing or overdeveloped, as if they were photographic film. We will for the moment adopt the classification. Developed countries usually have a high standard of living, are industrialized and have a large and sophisticated scientific and educational establishment. It is believed that both science and education are important ingredients of any policy designed to bring a developing country to development. This belief is naive from several points of view and should be carefully examined.

We noted above (16.2) that education is conservative by its very nature. All governments and all regimes tend to use the educational system of the country to guarantee their survival in power. If development of a society implies, as it often does, social changes which the ruling elite does not favour, then the educational system may be used to hinder, rather than help, development. This may be done in a subtle way, for example, by supporting education strongly but only in certain fields of study considered 'safe' (physics is usually considered safe). In other words, education may be used to define what kind of development occurs, and this may be a very partial kind, favouring only a limited social group.

The rôle of science, on the other hand, has also been under review. Investment in scientific institutes, both for equipment and for training of personnel, has been considered by economists an essential step in development policy. Recent research on this point, however, has shown that in many cases the money spent by developing countries on science has not brought appreciable returns. Science has turned out not to be an investment, but a consumable product from the economic point of view [19]. The scientific institutes and the scientists who received support did not always subsequently contribute to the solving of scientific and technical problems important for the country. They have often tended to work on problems fashionable in the international scientific community and of little interest to their own country.

Science is foreign to the culture of most developing countries. There is no scientific tradition in these countries. Science is an import like automobiles. It helps to establish new values in the country, it furthers the establishment of a different culture, tending to eliminate the indigenous culture in the process. Scientists in these countries are often connected more strongly to the international scientific community than to their own culture. (The existence of the international scientific community is one of the very positive consequences of scientific endeavour and has been important for scientists in developed and developing countries. However in the developing country the scientist must be very careful not to lose contact with his own community.) Perhaps one can draw an analogy between the influence of scientists in the developing countries today and that of the religious missionaries in the past. The aim is to eradicate old ways of thinking and to institute new ones, brought ready made from the developed countries. One may doubt whether such a transfer of science and technology is a good thing. Perhaps one should adapt one of Goethe's sayings: "What you inherited from your forefathers, conquer it that it may be your own". The ideas which you import from other cultures, conquer them that they may become yours.

On the other hand the developed countries themselves are facing a crisis. The high standard of living, the diminished hours of work and the greater leisure have not diminished stresses in society, but have perhaps made them more acute. It does not make sense to try to build, in the developing countries, the same society that is proving inadequate in the developed ones. One should try to profit from their experience.

Our theme is 'education for development'. What kind of development? The word usually implies economic development: a higher per capita income and more automobiles. That may not be the kind of development one wants, although undoubtedly the standard of living in developing countries must be raised. One would think that some of the mistakes of the developed countries – for example basing urban development on the automobile – might be avoided. Experience shows that this is not the case. In many countries the development which has occurred is more evident in an increased number of cars than in an increased average protein intake.

Issue 10: *How can physics education be organized in developing countries so as to contribute effectively to the progress of the country?*

16.8 POST-GRADUATE WORK

Post-graduate work has been described above as narrow and rigid, indoctrinating students with 'normal science' only (see 16.6). Another point is that in the developing countries the post-graduate schools are usually totally 'looking abroad', that is they tend to follow the developed countries and the scientific fashions of the day, having little connexion with the problems of their own countries (see section 16.7).

Post-graduate studies usually include some research. In order to obtain the degree and the corresponding privileges the student must present a thesis; he chooses a topic on which he will work for a few years and which will satisfy the examiners' requirement, that is their 'academic standards'. His aim is to obtain the degree. The relevance of the topic, be it to science itself (in the case of pure research) or to social needs (for applied work), is not important. The degree system thus spawns much irrelevant research.

It is argued that the work itself is not so important in this case, that the important thing is to assure that the student has learned in doing it and has demonstrated his ability to the examiners. This line of thought leads to the education of researchers estranged not only from social reality but from science itself. In effect, if it is necessary to train researchers it must be because there is relevant research to be done. It makes no sense to study irrelevant subjects.

Issue 11: *Is much of the research produced in post-graduate studies today irrelevant to the progress of science and to the needs of society and does it tend to produce alienated scientists? Should the choice of research topics be more careful?*

16.8.1 Working Group Comments

The working group at the Edinburgh conference commented as follows:

(a) The imposition of a scientific education developed in another country may well constitute a cultural invasion. This would occur if the content of the course, its technological applications and social implications were irrelevant or antagonistic to the country to which it was brought.

(b) At university level, the criteria which governs the choice of research topics should be the same as those in other fields of education, there should be the greatest possible freedom for the student and the teacher, although it must be understood that freedom implies responsible choice in the light of the wellbeing of the whole society. Some people expressed concern about the pressure on research students to indulge in excessive publications in the hope of promotion.

(c) It was recommended that physics at all levels of education should be appropriate to the culture in which it is being taught. Problems, examples and applications should be immediately relevant and educational methods should be efficient and realistic in the particular context in which they are to be used.

(d) It was agreed that research students should be helped to choose topics which are both a real development of physics and where possible make an effective contribution to life in the country in which the students are working.

16.9 NOTES AND REFERENCES

1. *Learning to be*, by a committee of seven: Edgar Faure (chairman), F. Herrera, A. Kaddoura, H. Lopes, A.V. Petrovski, M. Rahnema and F.C. Ward, Unesco, Paris, 1972.
2. Pierre Bertaux, quoted in *Learning to be* p. 57.
3. *Learning to be.* p. 59.
4. For example, earlier in this century in Brazil, a lay member of the ruling class was called either 'coronel' or 'doutor'. These titles did not imply that he had been an officer of the armed forces or had attended a university but they did imply that he belonged to the ruling class.
5. *Learning to be.* p. 59.
6. Ivan Illich. *Deschooling Society.* Harper & Row Publishers, Inc., New York. Also *Learning to be.* p. 20.
7. Actually the democratic system with universal suffrage was already a step in the direction of abolition of privilege: everybody has the same vote, independently of his education (although in many countries, illiterates do not vote). The question now is whether those who have received a longer education should have a right to a higher standard of living. The question is specially important in developing countries, where contrasts are sharper.
8. Hoyt, Donald P. American College Testing Program, Research Report no. 7, Sept. 1965.
9. The level after the first university degree, called graduate in some countries (e.g. the U.S.A.) and post-graduate in other countries.
10. The spiral approach, defended in physics by Al Baez among others, proposes a gradual deepening in the treatment of each subject in successive passages through the subject. Few would quarrel with this proposal, providing the spiral is not too wide, i.e. the time between successive passages is not too long, and the final level is deep enough.
11. *Learning to be.* p. 6.
12. *Learning to be.* p. 26.
13. *Learning to be.* p. 139. Freire, P. in *Cultural Action for Freedom* and *Pedagogy of Oppressed*, Herder & Herder, New York, 1970.
14. This conception of education was clearly described by Charles Dickens many years ago, in the novel *Hard Times:* Mr. Gradgrind, addressing the assembled pupils of his school, says: "Now, what I want is Facts. Teach these boys and girls nothing but Facts. Facts alone are wanted in life". And Dickens continues: "The speaker, and the schoolmaster and the third grown person present, all backed a little, and swept with their eyes the inclined plane of little vessels then and there arranged in order, ready to have imperial gallons of facts poured into them until they were full to the brim".

15. Even at the post-graduate level, however, physics education is often authoritarian, as discussed in section 16.8

16. A good short account of the controversy is given by B. Easlea – *Liberation and the Aims of Science,* Sussex Univ. Press, 1973.

17. Kuhn, T.S. *The Structure of Scientific Revolutions,* Univ. of Chicago Press, 1971, p. 138 and 166.

18. *Learning to be.* p. 65. B. Easlea. ref. 16. A Koestler – *The Sleepwalkers,* Hutchinson, London, 1959.

19. Cooper, C. *World Development* 2 (1974) 55.

17 Science and society – Scientific and technological aspects of current problems of society

In this chapter, originally written by J.M. Fowler, two aspects of 'science and society' activities are examined: the 'Science and Society' course and the science-society organization. The course seems to be largely an American phenomenon brought into existence as much by the drop in enrolment in physics classes as by conscious curricular design. References are provided for descriptions of over 50 'Science and Society' courses and an approximately equal number of 'Physics and Environment' courses. Appendices provide sample reading lists and texts for both types of course.

17.1 INTRODUCTION

The interaction of science and technology with society is as old as history. From their indistinguishable beginnings science and technology have contributed both problems and solutions to the nurturing society. Aristotle and Galileo threatened as well as taught their contemporaries. Watt advanced thermodynamics and ushered in the industrial age with its potential and peril. Fermi opened up the nucleus to our understanding and took us into the even more disturbing 'Atomic Age'.

The process continues. The examples from our times are numerous and familiar. They need no listing; they can be read from any newspaper.

In the 'Atomic Age', involvement has been almost the norm. Lord Russell, Linus Pauling, Max Born, René Dubos, George Wald, Niels Bohr, Edward Teller and Hans Bethe are examples of outstanding scientists who are easily identified with both scientific contribution and social concern. However in the 1940's, 1950's and 1960's, the interaction of science and society was less a meeting of equals than a missionary-like activity. The conscience-driven or dedicated scientist (or the publicity-seeking one) went out of his laboratory and into a public forum to meet society and discuss its problems. This was an additional activity, and not part of his professional role or responsibility, for scientists did not in those days consider that discussing the scientific components of society's problems was appropriate for their classes, for graduate seminars, for professional society meetings or for journals.

Beginning in the late 1960's and accelerating in the 1970's the previous scientific purity of classroom and convention has been diluted. Courses on various social aspects of science are taught in United States, Netherlands, Swedish and British colleges and universities, and in many countries the philosophy and history of science, along with its social implications, are part of the training of school teachers. Scientists are widely engaged in efforts not only to popularize science for the public but to work with experts from outside the academic walls in the study of social matters related to science. In many countries, such as the U.S.A. and the Netherlands scientists are exerting strong influence on public policy in, for instance, the controversy over the use of nuclear reactions as energy sources. Topics such as the environmental impact of technology, the shortage of energy and other natural resources, population growth and so on are now included in courses and appear on the agenda of professional meetings as well as in research papers from physicists. The science-society interaction is no longer missionary-like; the congregation is gathered and the priests are busy. 'Science and Society' has been academized.

17.2 SCIENCE AND SOCIETY IN ACADEMIA

The formal appearance of courses and curricula labelled 'Science and Society' is relatively new. The programmes which appeared first were under the aegis of departments of political science and schools of technology rather than in the natural sciences. Recent surveys have revealed that interest has been increasing substantially.

In the spring of 1972 the staff of the Subcommittee on Science, Research and Development of the Committee on Science and Astronautics in the U.S. House of Representatives undertook a survey of education and research activities in the area of science policy. Their definition of science policy was:

> "science policy work is defined in its broadest sense to include factual, descriptive and analytical teaching and research on the relationship between science, technology and society. For the purpose of this questionnaire it includes one or more of the following subjects: science and government; technology and society; science and the humanities; technology at the Federal, State and local level and in industry; technology forecasting and assessment."

This survey identified 150 American universities and other educational and research institutions which had some science policy activity. About a third of the universities reported a formal programme. A survey of that study (and some additional programmes) was reported by Ezra Heitowit of Cornell University at the Joint Symposium of the American Association of Physics Teachers (AAPT) and the American Physical Society (APS) Forum on Physics and Society. The 116 formal academic programmes which Heitowit identified fell into the categories of Table 1.

TABLE 1

Public affairs, public policy	46
Science, technology and society (general)	30
Environmental studies	16
Ethical and human value implications	11
Future studies	4
Interdisciplinary studies	3
Technology assessment	2
Other	4

An international survey of research and teaching activities in the area of science policy was carried out by Unesco in 1970. The findings were reported in 'Science Policy Research and Teaching Units' (Report No. 28 of the Unesco series 'Science Policy Studies and Documents'). The survey contains annotations on 344 such units in 26 European and North American countries. The fields of interest fell into the categories shown in Table 2.

TABLE 2

Fields of interest

1. Philosophy (including methodology and logic) of science, theory of science
2. Ethics of science
3. Sociology of science
4. Classification of scientific fields and disciplines
5. Creativity and psychology of researchers
6. History of organization of science and of scientific communities
7. Organization, administration and management of research and development (including science and technology information and communication)
8. Economics, productivity, efficacity, financing, etc. of research and development
9. Statistics of science and technology
10. Planning of research and development, planning of human resources in science and technology, public policy for science and technology (including relations with education, economy, foreign affairs, industry, health agriculture, environment, etc.)
11. Technological forecasting, futurology
12. International science policies, international cooperation in science and technology, comparative study of national science policies
13. Legislation in science and technology
14. Transfer of technology
15. Assessment of technology
16. Science and society/popularization of science

17.3 PHYSICS COURSES

As far as this chapter is concerned the physics courses offered under the Science and Society rubric are more pertinent. Heitowit provided the following breakdown of the 1287 listed in the previously mentioned survey.

TABLE 3

Percentage Breakdown by Academic Department

Engineering	14	Political Science	8
Planning	5	Sociology/anthropology	5
Agriculture	4	History and history of science	4
Environmental studies	4	Life sciences	4
Physical sciences	3	Physics/astronomy	2
Chemistry	1	Business and public administration	3
Public affairs	3	Economics	2
Information/control/computer sciences, cybernetics	2	Philosophy	2
Law	1	Architecture and design	1
Natural science	1	Other departments (less than 1 per cent each)	14
Special programmes	13	Unspecified	7

It is apparent that, at least statistically, physics is not particularly important to 'Science and Society'. It accounts for only 2 per cent of the courses at the end of the 1960's and the first year or two of the 1970's. The impression that physicists are not involved in such activities is however changed if we look at more recent developments.

There has been a modest wave of course development in this area. Some idea of the present size of this wave can be gained from the study of innovations in physics teaching which Robert Tinker undertook for the AAPT in 1973. Volume 2 of this three volume series entitled 'Courses for non-scientists' contains a section entitled 'Physics and Society'. Descriptions of 49 courses appear under this heading and an additional 117 courses are reported without detailed description.

A popular theme for physics courses has been the environment. Under the section titled 'Physics of the Environment' in Vol. 2 of the AAPT survey 56 courses are described and another 148 indicated without description. The most popular theme of these courses is the energy crisis, followed by courses on pollution and on nuclear energy.

There are equally impressive stirrings of activity elsewhere as revealed in the working group concerned at the Edinburgh conference as described below.

Several universities in Sweden have developed energy courses. The one at the University of Umeo consists of a treatment of the physical aspects of energy followed by an equal concentration on its technological, socio-economic and political aspects.

'Science and Society' topics are also incorporated into a school curriculum project TRUAS-Physics (Television and Radio Education at Schools) developed in the late 1960's. This physics course for students at the Swedish secondary level (17–19 age group) consists of 40 television programmes and many of these dealt with topics which showed the interaction of physics with society.

The new Swedish 'Institute of Physics and Measurement' is planning an interdisciplinary research programme which is project-orientated and may have a 'science and society' focus. The undergraduate offerings will have a corresponding emphasis and will be appropriately problem orientated.

A cooperative programme between several British universities in the United Kingdom aims 'to introduce into degree courses in science an emphasis on the social aspects: the sociological, economic, technological and ecological effects of science in our environment and also, conversely, the effects and influences which society expects in science.'

Materials produced by SISCON (Science in a social context) will be used, it is hoped, by university lecturers and by those who train physical science teachers.

In addition to the SISCON project, many universities and schools in the U.K. have 'general studies' programmes which include 'Science and Society' topics. The Department of Liberal Studies in Science at the University of Manchester and the Science Policy Research Unit at the University of Sussex have been in existence since 1966. Surrey University offers a degree programme in 'Combined Studies in Science' which includes courses in physical science, science studies and science education. At Malvern College, a 'Science and Society' course of broad scope has been designed for students who have already taken the Nuffield O-level physics course.

In the Netherlands, there are several levels of activity. Most universities have non-compulsory lecture presentations on science and society topics. Lectures may be on specific topics or may survey the range of environmental problems. Many universities are now considering requiring physics students to spend 5–10 per cent of their time on the study of the interaction between physics and society. The University of Groningen has a PhD programme in which the research project may be applied to some current science-related social problem. There is much other similar activity in the Netherlands: the involvement of scientists in the nuclear energy controversy, and the production of a short course on 'Energy and the Environment' are some examples.

Norway has a comprehensive plan for its schools, devised by the Ministry of Education and confirmed by the Parliament, in which in addition to traditional subjects such as mathematics and science there are other themes which must be taught, including reference to the environment.

This is, of course, only a partial list of activities of an academic nature. There are equally important examples of direct interaction between scientists and the public on matters of joint concern. These will be discussed later. First, it is necessary to ask two basic questions.

17.4 WHY?

The reason why physicists should concern themselves with 'Science and Society' topics was summed up by the working group at the Edinburgh conference as follows: (1) Scientists must be made aware of the social impacts of their science, (2) Society must be made aware of the scientific components of social problems.

The first of these is concerned with the making of the 'Complete physicist'. He must be aware of the links between his science and the society in which he lives, in order that his science and the rest of his life are in harmony.

The second places a new responsibility on the scientist. To the two traditional responsibilities (i) the discovery of new knowledge (research) and (ii) the transmission of knowledge (teaching), is added (iii) the interpretation and dissemination of knowledge to the society which supports him.

It should be clear that these three responsibilities will not receive equal attention by most individual students; the balance between them will be as difficult to achieve as is the balance between the traditional two. The balance must, however, exist in the profession.

The responsibility to attend to the interaction of physics with society is most important in school science. It is only in the schools that physicists deal with all future citizens. Since a majority of the crucial decisions facing our societies in the future will have scientific components, it is important that citizens know and trust both science and scientists.

There is a reasonable hope that the deliberate inclusion of social concerns in physics classes will meet the needs of school students and surveys show that such students are now giving priority to such matters. The acceptance of this responsibility by school physics teachers may help reduce the present alienation from science. It is clear that many of the broad 'Science and Society' courses taught in the U.S. colleges are, at least in part, deliberately designed to bring students back into physics departments. This does not, however, seem to be a significant factor elsewhere in the world.

17.5 HOW?

At the Edinburgh conference, the working group concerned divided at this stage into three groups to discuss 'how' to start and 'what' to do. One group considered schools (primary and secondary education), another universities and colleges of education, and the third the education of the general public.

17.5.1 Schools

The human and social aspects of science (physics) should be woven into the fabric of all school courses: science must be taught as a human activity which has relevance to the individual in his social, physical and biological environment. As guidelines for the design of courses, the group made these suggestions: (1) The aims and objectives of the course should be clearly presented for teacher and pupil and should explicitly recognise the social themes as well as the scientific ones. (2) The assessment of both student and course achievement should test for the social objectives as well as the scientific ones. (3) The content must, at appropriate places, reflect the historical-human development of important ideas. Along with concepts and principles, the course should develop their impact on society, on industry, technology, communication, transport, sport, etc. It should show the interaction and overlap of scientific developments with social issues. The teacher should have the freedom to explore controversial issues.

In stating this last suggestion, several of the participants warned that 'explore' was meant to imply a scientific examination of issues and not a doctrinaire exposition of the teacher's own attitude. This guideline presents a challenge to the teacher.

17.5.2 Tertiary education

The major concern of this group was the education of physics students. In an earlier section reference has been made to responsibilities of physicists, including their responsibility to be aware of the interaction of physics with society and to help interpret this science to society. If this is to be a recognised part of the making of a physicist, it must be a part of the educational experience of students of physics. Several means of ensuring this experience were suggested.

(1) An advanced course in which physics students (and students from other courses as well) used their knowledge of physics and mathematics and their problem solving techniques (including modelling and computer work if available) to attack real social problems. This course would have the additional advantage of removing some of the unduly theoretical flavour of much undergraduate physics.

(2) A seminar for physics specialists which considered, from the point of view of science, current and, if possible, local social problems. Alternatively such a seminar might focus on such things as the Club of Rome reports 'Limits to Growth' and 'Mankind at the Turning Point' or Schumacher's 'Small is Beautiful'.

(3). An introductory-level course. This course could either survey a broad range of science/society topics or focus on a specific theme. Examples of such themes might be transportation or the management of natural resources.

There is a second important way in which a physics teacher instructs his students in how to be a physicist and that is by example. For this reason it is important that physicists themselves are involved in science/society activities either through their research or through other visible activities.

17.5.3 Education of (and by) the general public

The important direct interaction between the physicist and the public has not been discussed in detail so far. The working group was presented with several national examples which are now summarized.

Australia. The Australian Academy of Science for seven years has carried on a 'Science and Industry Forum' in which leaders from these two areas spend two days in an intense consideration of a current problem (the proper use of the Australian uranium deposits is one example). The results are published and also interpreted in a syndicated newspaper column. The Academy now plans to start a similar 'Science and Society Forum' bringing economists, politicians, environmentalists etc. together with scientists.

The Singapore Science Centre. This new science centre offers a series of lectures on 'Science and Society' topics (the sociological aspects of science, for instance) to school populations and to the general public. They have also produced several articles for magazines such as the *New Scientist, Nature, The Bulletin of the Atomic Scientists,* etc.

U.S.A. A feature of the interaction of science and the public in the U.S. over the past decades has been the interacting science organization. Two well known organizations of this type grew out of the psychological trauma of the atomic bomb project: the Society for Social Responsibility in Science (SSRS) and the Federation of American Scientists (FAS). The SSRS, which now has a modest international membership, speaks directly to the ethics of the scientist and has sponsored a number of activities to apply science and technology directly to social problems. The FAS directs its attention more towards the U.S. Congress and those who control policy-making through careful in-depth analysis of current scientific-political problems.

In the 1960's other organizations developed which were intended to increase the direct interaction between scientists and the public. One such organization in the United States, the Scientists' Institute for Public Information (SIPI) was founded in 1963 as a loose federation of local 'Science information groups'. SIPI publishes the magazine *Environment* and supports a variety of local groups of scientists and citizens who deal with local issues; for example, air pollution in St. Louis, reactor siting and pesticides in California, etc. SIPI maintains a speakers bureau and creates ad hoc task forces to deal with specific issues.

There is another organization now visible at professional society meetings, Scientists and Engineers for Social and Political Action/Science for the People (SESPA/SFTP). This loosely structured group was formed in 1969 and is a latter day SSRS although much more action orientated and political. Its target seems to be the scientific-technical community itself and its publications analyse and criticise, for instance, the close ties between the scientific-technical 'establishment' and the corporate and governmental ones.

These organizations and the others like them offer scientists a chance to work directly in the public forum in policy over problems and policy matters. There are similar groups in other countries and some of the more prominent active groups are listed in Appendix II at the end of the chapter.

The working-group on science and public interaction made several suggestions for guidelines. They felt that it is important to recognise and be aware of the roles of different media and that the popularization of science should deal with science and society issues as well as with pure science topics. Useful mechanisms might include seminars for science writers, television producers, museum directors, lecture agencies and so on. It is of course important in these exchanges that the scientists themselves are seen to be willing to consider social issues from the viewpoint of other experts. Finally it was pointed out that the science-society interaction could be made more visible to policy makers in government positions by planning programmes which would provide non-partisan advice on these matters for official bodies. It is recognised that political considerations could not (and perhaps should not) be excluded from these discussions and there is a risk of generating some political controversy in any attempt to illuminate such matters. Nevertheless the group felt that more discussion of these topics would be regarded by most people as being in the public interest.

17.6 SCIENCE AND SOCIETY IN THE DEVELOPING COUNTRIES

One of the distinct features of the working group was the scarcity of participants from developing countries: Bangladesh, Singapore and the Republic of Korea alone were represented. The opinion was put forward that a concern over the interaction of science and society was a luxury which could only be afforded by scientists from the developed nations. The few participants from developing countries insisted, however, that such an interpretation missed an important point. It may be true that science education develops in stages and that the emphasis of the first stage is necessarily on basic education in science. However scientists themselves in developing countries are more likely to be *engaged* in the social interactions of their science than are scientists in developed countries. They are working, for example, on flood control, on food preservation or on the development of new energy sources. While their students may not receive deliberate instruction in 'Science and Society' topics they receive something which may be more important, namely a living example. The scientist himself quite often provides a model of the complete physicist. Far from a luxury, the science-society interaction in a developing country may be such a necessity as to be too obvious for formal attention to be called to it in the classroom.

17.7 CONCLUSION AND RECOMMENDATIONS

There is one general recommendation, guideline or caution which the working group was anxious to see applied generally to all the endeavours to bring science and society together. There is a need to realise that *science is not always able to give the right answer.* The complete formulation would be that science is not always able to give the right answer, but just as often the right answer cannot be obtained without science.

It is important to emphasise the limitations of science as well as its strengths. As Weisskopf said in his address to the conference, while science can be described as a complete structure it is not all-embracing. There are vast areas of human experience which fall outside its scope. However many of the problems which society faces fall across the boundary which separates the two areas. Solutions to such problems therefore require an input from science but that input does not determine the answer. Many of these problems are best subjected to a cost/benefit analysis; science can delineate some of the costs (can describe radioactive wastes or give probabilities for reactor accidents, for instance) and describe some of the benefits (efficiency of energy conversion, extension of resources). However, it cannot define the rate of exchange at which benefits are bought and costs assessed. It is most important that the scientist, whether he is interacting with school or college students or with the general public, draw attention to the boundary of science and divest himself of science's authority when he crosses that boundary.

The working group agreed on certain further recommendations:

(i) Teaching journals in all countries should encourage the preparation of articles on 'Science and Society' topics.

(ii) All professional organizations in physics should give space and time to presentations in this area.

(iii) In those educational systems in which students are asked to comment (by questionnaire, for instance) on the performance of teachers, the question 'Did the lecturer discuss the social relevance of his physics?' should be asked.

(iv) Communication between scientists who are involved in 'Science and Society' activities should be stimulated.

In the furtherance of this last recommendation, the working group would like to encourage Unesco to undertake an international survey and annotated collection of 'Science and Society' courses. Unesco is also encouraged to devote some conference time specifically to this area of interest.

17.8 SUMMARY

Science and technology have designed and fuelled the vehicle that is carrying society swiftly toward the end of the twentieth century. The roadway which lies ahead is an increasingly rough and uncertain one. Scientists and engineers in the past have concerned themselves largely with engine performance and acceleration. In the last decade they have become more and more concerned with control, with steering and even with braking.

In the United States and to some extent internationally, these concerns are becoming professionalized. Programmes and institutes for the study of science and technology issues have been formed; undergraduate and graduate courses are being taught and research is being undertaken. Much of this activity is appropriate to physicists.

The appeal of this kind of professional activity is easy to understand. In it conscience and science can be legitimately joined. The formal academic programme or the science-society organization are thus natural extensions of the purer professional activities.

The inclusion of 'Science and Society' topics in an academic course is a more recent activity and more difficult to assess and codify. We hope this working group has helped in the necessary development. Such activities must continue. There is a generation which must be prepared for the end of the 'exponential' century and in this preparation the physicist can strengthen his own bonds with his society and its future.

17.9 APPENDIX I

Science and Society Journals

1. *The Advancement of Science,* British Association for the Advancement of Science, London. (In U.S.A.: Academic Press, Inc., 111 5th Ave., New York, New York 10003.)
2. *Atomic Scientists Journal,* Taylor and Francis, Ltd., Red Lion Court, London, EC4, England.
3. *Daedalus,* Journal of the American Academy of Arts and Science, 280 Newton Street, Brooklyn, Massachusetts 02148.
4. *Energy Conversion, An International Journal,* Pergamon Press Ltd., Headington Hill Hall, Oxford, England.
5. *Energy Policy,* A new international journal on the economics and planning of energy. ICP Science and Technology Press, Ltd., ICP House, 32 High Street, Guildford, Surrey, England. (In U.S.A.: IPC (America) Inc., 205 E. 42nd Street, New York 10017.)
6. *Environment,* Scientists' Institute for Public Information, P.O. Box 755, Bridgeton, Missouri 63044. (For information write to 438 Skinker Blvd., St. Louis, Missouri 63130.)
7. *Impact* of Science on Society, Unesco F-75700 Paris, France.
8. *The International Journal of Environmental Studies,* Gordon & Breach Science Publishers, 42 William IV Street, London WC2, England.
9. *Journal of Environmental Sciences,* Institute of Environmental Scientists, Mt. Prospect, Illinois.
10. *New Scientist,* New Science Publications, 128 Long Acre, London WC5, England.
11. *Science and Culture,* Indian Science News Association, 92 Acharya Prafullachandra Road, Calcutta 9, India.

12. Science and Public Affairs, (formerly *Bulletin of Atomic Scientists)* 1020-24 East 58th Street, Chicago, Illinois 60637.
13. *Search,* Journal of the Australian and New Zealand Association for the advancement of Science, Science House, 137 Gloucester Street, Sydney 2000, Australia.
14. *Technology Review,* MIT, Alumni Association, Room E19-430, Cambridge, Massachusetts 02139.
15. *Technology and Society,* Unesco, Place de Fontenoy, F-75700 Paris, France.
16. *Technology and Society,* Bath University Press, Northgate House, Upper Borough Walls, Bath, England.

17.10 APPENDIX II

National and International Organisations

1. Federation of American Scientists (FAS). Jeremy Stone, Director, 307 Massachusetts Avenue, N.E. Washington D.C. 20002, U.S.A.
2. International Commission for Science Policy Studies. Derek de Solla Prince, President. Department of History of Science & Medicine, Yale University, 2036 Yale Station, New Haven, Connecticut 06520, U.S.A.
3. International Co-ordinating Committee for the Presentation of Science and the Development of Out-of-School Scientific Activities (ICC). F.L. Wattier, Secretary General. Rue de Veeweyde 125 (Bte 7), B-1070 Bruxelles, Belgium.
4. International Council for Scientific Unions (ICSU). F.W.G. Baker, Executive Secretary. 51 Bvd. de Montmorency, F 75007 Paris, France.
5. Pugwash Conferences on Science and World Affairs. Prof. J. Rotblat. Secretary General. 8 Asmara Road, London NW2.
6. Scientists and Engineers for Social and Political Action/Science for the People. 9 Walden Street, Jamaica Plains, Massachusetts 02130, U.S.A.
7. Scientists' Institute for Public Information (SIPI). Alan McGowan, President. 30 East 68th Street, New York, New York 10021, U.S.A.
8. Society for Social Responsibility in Science (SSRS). 221 Rockhill Road, Bala Cynwyd, Pennsylvania 19004, U.S.A.
9. The British Society of Social Responsibility in Science, 9 Poland Street, London W1V 3DG.
10. Liaison Committee of the World Assembly of NGO's (Non-governmental organisations) concerned with the Global Environment. Sec: Cyril Ritchie, ICVA, 7 av. de la Paix, Ch-1211 Geneva, Switzerland.
11. International Union for Conservation of Nature and Natural Resources (IUCN). Dr Gerardo Budowski, Director General. Ch-1110 Morges, Switzerland.
12. International Youth Federation for Environmental Studies and Conservation (IYF). Gerhard Walter, Secretary General. Radergunderstrasse 6, A-8045 Graz, Austria.
13. Sierra Club. Office of International Environment Affairs. Patricia Rambach, Int. Officer. 777 United Nations Plaza, New York, New York 10017, U.S.A.
14. United Nations Environment Programme (UNEP). Maurice F. Strong, Director. Nairobi, Kenya.
15. World Office of Information on Environmental Problems. Dr Richard Abbor, General Delegate Chairman. 115 rue de la Pompe, 75116 Paris, France.

18 Out-of-school science activities

This chapter is based on a very much longer report submitted by Francis L. Wattier, the Secretary-General of the International Coordinating Committee (I.C.C.) for the Presentation of Science and the Development of Out-of-School Scientific Activities. Such activities represent a new pedagogical approach in the educational process and consequently, with a few notable exceptions, have only a short history (10 or 15 years at most). It is therefore somewhat premature to comment on the physics component of these activities. There will certainly be more to say in future years.

18.1 CHARACTERISTICS OF OUT-OF-SCHOOL SCIENCE ACTIVITIES

There are various types of out-of-school scientific activities and these are discussed below. Most of them are concerned with creative ability to enable individual aptitudes to develop. There is direct participation by young people at every stage of this educational device: choice of the field of interest, determination of the methods of observation and analysis, the planning of laboratory studies, the preparation of individual reports and also active contribution to 'group' activities.

Programmes are usually conceived on an inter-disciplinary basis so that topics can be considered in a wide context and early specialisation avoided. The activities strive not only to improve scientific and technical knowledge, but also to show relevance to socio-economic development. They provide for young people still at school, as well as for those who have already left and are now young farmers, apprentices, workers and so on.

18.2 SCIENCE CAMPS

Science camps – sometimes in tents, sometimes on permanent sites – are mainly organized to teach the application of science to nature, to acquaint participants with the general ecology of the particular region and the place of their speciality within it, whether that speciality be botany, zoology, physical geography, anthropology (sociology), geology, meteorology, chemistry or physics applied to nature conservation. These camps help to foster contacts between young scientists and reveal the interdependence of the specialities through interdisciplinary tasks.

Their success depends on various factors, in particular the number and quality of the staff, the quality and the amount of scientific equipment, the care taken over the working programme, the choice of site. Of course it is necessary to adapt the programmes and the methods used according to the participants, whether they are students or apprentices, whether or not they have a rural background, whether they have scientific training or are non-specialists in science.

Various activities in the field (trips, observation and collection of material) and in the laboratories of the camp (experimental work, group discussion, reporting on results) greatly develop the sense of observation, the sense of initiative, the feeling of individual responsibility within the group. There is also the fun of common life, the richness of human contact, the effective practice of real dialogue, and the sense of unity among young people of different outlook.

Some associations organize local, national or international camps to complement the traditional formal education in science, others are directly integrated into a larger programme to consider some specific problem, for example the social factors determining the conditions of life of certain populations or problems concerning humanity such as environmental pollution, population explosion or the shortage of food.

Usually, it is quite difficult to determine with precision the physics component in these activities since, more often than not, they are carried out within a multidisciplinary pattern. But the following all have a physics component. (a) *The Association Nationale des Clubs Aerospatiaux* in France is coordinating a project to construct and test a rocket (statement of preliminary project, detailed study and mock-up construction, flight model construction, payload specification, actual-launching, analysis of results); (b) the 'Science for Children' Association in Calcutta has a hobby centre with facilities for the construction of simple scientific models and for project work in physics, chemistry, biology and astronomy; (c) the 'Summer Science Camp', organized annually by the Weizmann Institute of Science in Rehovot, Israel, has three specialized groups in physics: modern physics (theory), elementary particles (theory and experiment), lasers (theory and experiment); (d) the 'School Science Field Work Centre' of Thondaimannar in Sri Lanka organizes camps on improvization of apparatus for teaching science; (e) the 'Al-Ahram Science Clubs' in Egypt organize science camps which include working groups on electronics, meteorology and photography; (f) the Yugoslav movement 'Nauku Mladima' (Youth and Science) organizes numerous camps on astronomy, electronics, technical radio, astronautics; (g) the *Jeunesses Scientifiques de Belgique* have free entrance to the university laboratories to hold their annual training courses in theoretical and experimental physics, as well as for their computer training courses.

18.3 SCIENTIFIC AND TECHNICAL CLUBS

The science club is a voluntary group of young people, the purpose of which is to allow its members to enlarge their scientific and technological knowledge and experience through experimental work, discussions, debates, conferences and other activities, such as the publication of science bulletins, visits, scientific film shows, the making of scientific models and apparatus, the execution of projects.

The structure and work of science clubs depend largely on local conditions. Sometimes they work in close relation with schools, sometimes they are completely independent. It is always important that the programmes of the clubs have a real science content and the leaders need to be well informed.

Some clubs are very general in outlook covering all the scientific disciplines, others are specialized. The latter make organization easier but cater less for the wide interests of young people. Some clubs have a number of rooms for laboratories in physics, chemistry, biological sciences and electronics, some have rooms for exhibition and collection of materials, some a mechanical engineering workshop or even a small observation tower for astronautical work. All the clubs have as their objective the awakening and development of scientific interest, and one of their main aims should be to show that *science is something which is done*, not merely something which is learnt. It is hoped that young people will appreciate that an experiment is designed and undertaken to find out something which is not known, it is not to confirm a result already known in advance!

Clubs for children at the elementary level often aim to stimulate curiosity about the environment without any special reference to physics. At higher levels, a definite physics component is easier to recognise, as for example in the radio and aeromodel clubs in the USSR, the clubs for audio-visual techniques in India, the space clubs in Singapore, the rocketry associations in France, Chile, Poland, Spain, the USA, the Federal Republic of Germany and the Democratic Republic of Germany. Many clubs show a keen interest in social implications, for example a study of radioactivity in water.

In the developing countries, clubs located in rural areas are also trying to develop a scientific attitude among villagers. An example is the School Science Field Work Centre in Sri Lanka, where the clubs try to build equipment with the material they can find directly in the village, e.g. a homemade refrigerator. Further examples of typical achievements include the following: (a) the clubs for cybernetics in Ukraine are working in close collaboration with the Cybernetics Institute of the Academy of Sciences of Ukraine; the members of these clubs have, for instance, designed and built computers such as 'Kostyor' and 'Iskra'; (b) since 1966, the *Estudiantes de Ciencias Luis Pasteur* association in Venezuela has had an electronics programme; (c) the *Jeunes-Science* movement in Upper Volta has a particular group especially devoting itself to physics and during the scientific fortnight organized once a year since 1970, 45 per cent of the projects presented by the participants dealt with physics; (d) in the U.S.A., the JETS Association (Junior Engineering Technical Society) is leading a network of clubs for young people particularly interested in engineering sciences and techniques; (e) the laboratory-club *Jeunes-Science* in Tunisia has laboratories for chemistry, biological sciences, physics-electronics, a workshop for mechanics and two collecting rooms; (f) the 'Jets of Zambia' Association (Junior Engineers Technicians and Scientists) is concentrating on stimulating the interest of young people towards physics through activities and projects achieved within its clubs. The most developed and frequented science clubs are those dealing with radio, electronics, mechanics and aeronautics. This tendency is increasing and the proportion of young candidates choosing physics reads as follows: 1972, 38 per cent; 1973, 47 per cent; 1974, 52 per cent.

18.4 SCIENCE CONGRESSES, MEETINGS, SEMINARS

In Latin America, some associations have organized science congresses (*congresos cientificos de jovenes*) for the purpose of giving young people an opportunity to present scientific work before a qualified audience. The experts judge these works according to their originality and the methods used and can discuss them directly with the young investigators.

Other countries have organized national or international meetings of young scientists, seminars for young scientists, science forums and so on. These help to make young people aware of the role they are bound to play not only to ensure their own personal future, but also to contribute to the well-being of mankind. Concern with community development programmes provide a medium for direct action.

Examples of such meetings include the following: (a) the international meeting held at Göteborg (Sweden) in August 1971, on the theme 'Youth and water pollution'; (b) the European Conference 'Youth and Space' held at Marly-le-Roi (France) in 1972, at Belgrade (F.S.R. of Yugoslavia) in 1973 and at Madrid (Spain) in 1975; (c) an Asian youth seminar held at Thondaimannar (Sri Lanka) in August 1974, together with an exhibition of science projects on the theme

'Youth and environment: green revolution'; (d) each year the London International Youth Science Fortnight gathers more than 400 boys and girls, to help them acquire a better appreciation and understanding of the social implications of science for the well-being of mankind; (e) since 1967, the *Coordinatie commissie voor wetenschap buiten schoolyerband* (coordinating commission for out-of-school science activities) in the Netherlands has regularly organized on a national basis scientific days and week-ends on themes such as energy, computers and pollution; (f) as an example of regional activity, there was the South American meeting on 'Science and Youth', held at Olavarria (Argentina) in September 1973 to stimulate out-of-school science activities.

In order to meet the needs and aspirations expressed by youth, it is suggested that seminars at regional and international level might be held on such themes as Youth and electronics, Youth and oceanography, Youth and cybernetics, Youth and ecology, etc.

18.5 COMPETITIONS AND SCIENCE FAIRS

Another means of promoting out-of-school science activities are science fairs, which provide an opportunity for young people to show project work. It stimulates interest and encourages self-confidence especially when young people have to explain their projects to others.

In some countries there is a competitive aspect in that projects are judged by a jury of experts who assess the originality of the work, the scientific content, the creative thinking, the visual presentation and the results obtained. In Zambia, for example, the winners of the regional science fairs organized by JETS are invited to take part in a national congress during which they present their projects and reports. The best is chosen as the 'young engineer of the year'.

Young people often present projects related to the problems encountered by the community in which they live (for example, problems concerned with air or water pollution). In all countries, but more particularly in developing countries, projects are often concerned with social and economic development (for example, comparison of the growth of food plants in various soils). Science fairs can have a particularly important role in developing countries because the young people concerned participate directly in the dissemination of a scientific attitude in their community.

A survey reveals that there is always a strong physics component at science fairs: over 60 per cent of the projects in the science fairs in Egypt organized by Al-Ahram Science Clubs, 28 per cent of the projects at the Swiss science fairs, 45 per cent of the projects at the Scientific Fortnight held annually at Ouagadougou, Upper Volta. At the fourth annual science fair in Ghana, five out of the 12 winning projects were in physics; in Canada 35 out of 134 projects concerned physics. Every year, national competitions are organized in various socialist countries in Eastern Europe (USSR, Rumania, Yugoslavia, Hungary, Czechoslovakia): on such occasions thousands of projects are presented in various fields relating to physics and technology.

Science fairs have been organized by the Science Foundation of the Philippines, by the Unga Forskare Foundation in Sweden, by the Science Clubs of Thailand, by the Science Service of the USA, by the Jugend Forscht Foundation in the Federal Republic of Germany, by the Mexican *Consejo Nacional de Ciencia y Tecnologia* and the American Association for the Advancement of Science in Mexico, by the Association of Science Teachers in Ghana and by the British Association of Young Scientists (BAYS) in the United Kingdom.

18.6 POPULAR SCIENCE CENTRES AND MUSEUMS

It is now generally accepted that scientific and technological museums might be more than collections of objects. They might become more and more closely integrated with educational needs, both of school children and the public at large.

Consequently, it is particularly important to seek out every means of extending science museums to become 'popular science centres', where activities such as science clubs, exhibitions of scientific projects, competitions, courses, public lectures and the lending of materials may be developed.

In India, the main science museums and the planetaria are situated in the big towns. In order to extend the benefit of the museums to rural populations, therefore, the Birla Industrial and Technological Museum (BITM) of Calcutta has developed the idea of mobile museums. These travel throughout the country carrying science fairs. Demonstrators are responsible for these 'buses' and explain the exhibits in the local languages. By further improving the quality and quantity of these demonstrations, such 'museobuses' can be an important instrument for the progagation of science among young people and rural populations. The BITM has been financed by the Council of Scientific and Industrial Research under the Ministry of Education of the Indian Government.

To create scientific awareness among the lay public, this museum has set up several exhibits devoted to such branches of science and technology as: nuclear physics, mining, copper, iron and steel, petroleum, electricity, television and electronics, transformation of energy, communication and transport. These exhibits are mounted on the specially equipped buses which serve as exhibition halls.

A promotion centre for creative abilities has been set up at the Birla Industrial and Technological Museum to encourage students to develop their scientific aptitudes by producing scientific devices and equipment. The museum also organizes yearly *viva voce* competitions and science fairs for students.

Another action initiated and developed for rural areas is the establishment by the National Council of Educational Research and Training (NCERT) of science centres (Vijnan Mandirs) in various villages of India; the purpose is to popularize science by demonstrations and to show its applications to daily life. Unfortunately the multiplication of these science centres is limited because of shortage of both financial means and of qualified people to maintain them.

18.7 SCIENTIFIC OLYMPIADS

This form of science competition (physics, chemistry, mathematics, biology) is based mainly on the experience acquired by the socialist countries of Eastern Europe.

The purpose of these competitions is to encourage students to increase their knowledge, to create conditions favourable to non-directed work and to stimulate scientific talent. In some countries, the winners of the national olympiads have access to university colleges without entrance examination.

The participants are usually chosen from secondary schools. Because of the different levels of the participants, the olympiads are often divided into various categories. In one particular olympiad designed for students of the final secondary forms, the competition was divided into three stages: local, regional, national. The candidates who succeeded in the local and regional competitions participated in the national olympiad, divided into two parts: theoretical (solution of an original problem) and practical (practical work in laboratories, on a proposed theme, the same for all).

Winners of the olympiads are then given an opportunity to attend special courses in the discipline they have chosen. They also represent their country in the International Olympiad, organized every year in order to contribute to international exchanges in the field of science education.

The first International Physics Olympiad was held in Warsaw in 1967 and since then the International Physics Olympiad has been held annually, usually in the capital city of one of the socialist countries in Eastern Europe.

There are also other forms of competition, such as the physics contest organized each year for more than half a century by the Hungarian Eötvös Physics Society. In these contests, students from high school and college levels have to solve various physics problems. This contest provides an opportunity for detecting and encouraging talented students.

Another type of annual olympiad has been organized since 1967, by the Coordinating Commission for Out-of-school Scientific Activities in the Netherlands. After four years, the approach was modified: the organizers are now trying to arouse interest among young boys and girls (15 and 16 years old) not particularly talented in the physical sciences. The basic objective is now to show the social implications of the physical sciences.

18.8 SCIENCE TALENT SEARCH SCHEMES

At a time of rapid progress in science and technology, the search for scientific talent in young people is becoming a preoccupation among some educational and scientific authorities. Every opportunity is given to talented young people to develop their aptitudes, to stimulate their sense of creativity and to encourage them to continue with further scientific studies. Various national associations have set up programmes for the award of scholarships to a certain number of selected students who have real scientific ability.

18.9 PEDAGOGICAL SUPPORT

Many organizations of young scientists publish special periodicals for their members. (In 1975, the *Conseil de la Jeunesse Scientifique du Québec* in Canada published a directory of books and periodicals accessible to young scientists, comprising 1831 volumes and 160 periodicals). Some associations publish special leaflets and handbooks which can help with project work.

The ICC international journal 'Out-of-school scientific and technical education' [1], published with the assistance of Unesco in four languages (English, French, Spanish and Arabic), includes pedagogical notes to help science clubs and others. Typical examples include 'How to design, construct and test a rocket' and 'How to establish and run an astronomical club'.

Support for activities also comes from science kits. At the elementary level it is not necessary to use elaborate materials, but science is a form of play and a box of simple equipment can be a valuable aid in the classroom or club. Such kits have been produced by the Brazilian Foundation for the Advancement of Science Education (FUNBEC) in Sao Paulo (they cover over 100 different topics, for a wide age range of young people), by the Science Service in the USA, by the Birla Industrial and Technological Museum in Calcutta. The JETS Association in Zambia has a special programme 'Production-Technology': the ZAMKIT project has enabled much equipment to be produced. This list is certainly not exhaustive as many associations produce or use science kits.

Finally mention must be made of the support that can be provided by films, audio-visual aids, radio and TV programmes. ICC is working with Unesco in producing a directory of material likely to be useful in out-of-school activities.

18.10 CONCLUSION

Out-of-school activities can help to produce more critical, analytical and logical attitudes towards science. These could help remove the 'supernatural' or magical elements still associated with science in some countries, while producing a more balanced view in other countries where students associate many of the evils of the modern world with science.

There is an urgent need for equipment and other resources, as well as for good people to organize activities. It is important for universities, for museums and for industrial concerns to appreciate the role they can play in promoting activities. There is a need for school authorities to appreciate the advantage of using school equipment and school facilities for out-of-school activities, not only for the sake of those activities but also because involvement in such activities can do much to enhance the quality of in-school science teaching.

Recognising the high educative value of these activities, it is recommended that in future more attention be directed to the out-of-school component of science education. The attention of governments should be drawn to the need for and the value of setting up national bodies for promoting and coordinating public understanding of science and technology. It has also been suggested that IUPAP should be invited to consider more systematically this out-of-school aspect of the educational process.

More experience is needed, but the initial work done by the ICC encourages the belief that much can be achieved in the future.

18.11 BIBLIOGRAPHY

1. *Out-of-school scientific and technical education:*

   International journal published with the assistance of Unesco, in four editions: Arabic, English, French and Spanish, by the International Coordinating Committee for the Presentation of Science and the Development of Out-of-School Scientific Activities (ICC).

   Obtainable from ICC, 125 rue de Veeweyde (Bte 7), B-1070 Brussels, Belgium.
2. Handbook prepared by ICC and published by Unesco, *"Out-of-school scientific activities for young people"*, author: Mr. R.A. Stevens, past President of ICC. 3 versions: English, French, Spanish (1970).
3. First essay into a directory prepared by ICC for the Unesco Division of Methods, Materials and Techniques: *"Mass Media and Scientific Mind among Young People".*

19 Women in physics and physics education

In some countries the number of girls studying physics and the number of women teaching and doing research in physics is surprisingly small. This chapter, based on a paper written by Alison Kelly, examines the reasons and suggests some ways of encouraging more girls to study physics.

19.1 INTRODUCTION

Since 1901, 101 Nobel Prizes in physics have been awarded. Only two of these have gone to women (Marie Curie in 1903 and Maria Geoppert Meyer in 1963). In England and Wales in 1972, 116 825 children took physics O-level. Only 21 per cent of these children were girls. Why, at all stages from O-level to Nobel Prizes, are women so under-represented in physics? This chapter goes some way towards answering this question by examining the position of women in physics in different parts of the world, and by suggesting some steps which physicists might take to encourage more women to enter their discipline.

Women's position in physics is a reflection of their position in society as a whole. But over and above this there are special problems in physics, which centre on society's expectations and attitudes towards girls in science. The most effective solution would be to alter these attitudes, but it is more relevant in this chapter to concentrate on remedies within physics itself, for two reasons. First, the effect of outside pressures on women physicists has been fully aired elsewhere and, second, because physics in the classroom reflects those outside pressures, we should as physicists be concerned with setting our own house in order.

This chapter begins with a survey of international statistics, which identifies those regions of the world in which women physicists face special problems. The rest of the chapter concentrates on these areas and suggests some possible causes and remedies for the situation. It focuses on factors affecting younger children – those in the first few years of secondary school – since if a girl drops out of physics at this stage she is most unlikely to take it up again later on.

More women should be involved in physics. This is not a demand for quotas, but for steps to encourage girls' interest in, and enjoyment of, physics, so that they want to become involved in the subject. If physics is seen as an integral part of a general education, taught for the intellectual satisfaction and excitement it provides, it should be made available in a way which appeals to both girls and boys. If it is taught to non-specialists because they will live in a technological society (and future citizens need to be able to understand and control their environment) this applies to girls and boys alike. If the aim is to produce future research physicists, then the source of potential talent must come from both girls and boys.

19.2 COMPARATIVE DATA ON WOMEN SCIENTISTS

An examination of the representation of women in physics in different countries provides a starting-point for establishing where a problem exists and also its magnitude. Unfortunately, international statistics are rarely broken down both by sex and by detailed subject area, so comparative data is presented here for women scientists rather than for women physicists. Table 1 shows the mean percentage of students of natural science, engineering and medicine who are women, in six regions of the world. The figures for engineering and medicine are included for comparison since these are also science-based disciplines. Biology and, to a lesser extent, chemistry are more popular with women than physics, so these figures for natural scientists will over-estimate the percentage of women physicists. But they do give a rough idea of the situation in different regions of the world.

Table 1. Mean number of women students at tertiary level expressed as a percentage of the total number of students in six regions of the world.

Region	**Percentage of women at the tertiary level in different disciplines**			
	natural science	engineering	medicine	all tertiary education
African (13)	9.5	1.4	14.9	12.8
Arab (11)	22.6	3.5	27.7	22.5
Western*(22)	25.0	3.9	31.6	33.8
Asian (15)	28.6	4.3	34.6	28.1
Central & S. American (14)	44.6	5.8	41.7	35.0
East European (9)	49.1	22.0	58.3	42.3

*In the absence of any more suitable term, the word Western has been used throughout this chapter to designate countries where the culture is predominantly that of Western Europe.

Notes

(a) The data refer to the years 1969, 1970 or 1971.

(b) Appendix Table A1 gives the breakdown for each country.

(c) The number of countries in each region is given in brackets after the name of the region.

This table must be interpreted with caution. International comparisons of this kind are always suspect, because different countries may use different definitions in spite of the compiler's efforts at standardization. Thus in some countries those studying to become science teachers are included under natural science, whilst in other countries they are classified under education. The proportions of biologists, chemists and physicists in 'natural science' may vary widely from country to country. And the 'medicine' category appears to include student nurses as well as trainee doctors in at least one or two cases. However the process of averaging by region probably smooths out the worst of these discrepancies, and the results certainly warrant discussion.

Table 1 shows that the percentage of natural science students who are women ranges from under 10 per cent in Africa to nearly 50 per cent in the countries of Eastern Europe. In engineering it ranges from 1.4 per cent to 22.0 per cent and in medicine from 14.9 per cent to 58.3 per cent. When arranged according to the percentage of women students, the six regions appear in the same order for all three science-based disciplines with the smallest percentage of women scientists in Africa, followed by Arab, Western,* Asian, Central and South American countries. The largest percentage of women scientists is in East European countries. But this order does not exactly match the order in all tertiary education where Western countries have a higher percentage of women students than Asian countries (last column, Table 1). If the percentage of women in all forms of tertiary education is taken as an index of the position of women in society, this can be compared with the position in science. Table 2 shows such comparisons. The percentage of women in each of the science based disciplines has been divided by the percentage of women in tertiary education as a whole. Ratios of less than one indicate subjects in which women are under-represented (when their position in tertiary education as a whole has been taken into account) whereas ratios greater than one indicate subjects in which women are relatively over-represented.

Table 2. The relative representation of women in science-based disciplines compared with their representation in all tertiary education in six regions of the world.

	natural science	engineering	medicine
African	.74	.11	1.16
Arab	1.00	.16	1.23
Western	.74	.12	.93
Asian	1.02	.15	1.23
Central and S. American	1.27	.17	1.19
East European	1.16	.52	1.38

Notes

(a) The figures are $\frac{\text{Percentage of women students in the discipline concerned}}{\text{Percentage of women students in all tertiary education}}$

(b) This Table is derived from Table 1.

Clearly the sex-typing of science varies in different regions of the world. Only in Western and African countries are women proportionately under-represented in natural science. In Arab and Asian countries, the percentage of women in science matches the percentage of women in tertiary education; and in Central and South American and East European countries women are proportionately over-represented in science. In both regions, women still form less than 50 per cent of science students, although science is rather nearer equality than is tertiary education as a whole. Engineering and medicine present strong contrasts. In all regions of the world, women are drastically under-represented in engineering; the situation is markedly better in Eastern Europe than elsewhere although even there women are only half as well represented in engineering as in other subjects. However, in most regions of the world women are better represented in medicine than in other subjects (Western countries are the exception). Nevertheless, only in Eastern Europe do women constitute a majority of medical students.

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*In the absence of any more suitable term, the word Western has been used throughout this chapter to designate countries where the culture is predominantly that of Western Europe.

Table 3. Comparison of the percentage of women students in the early 1970's with the corresponding percentage in the early 1960's.

	natural science	engineering	medicine	all tertiary education
African (6)	10.8 (9.4)	0.5 (0.1)	19.5 (9.7)	14.2(11.1)
Arab (8)	19.0(13.3)	4.6 (3.0)	24.1(24.7)	17.9(12.9)
Western (21)	25.6(23.8)	3.9 (2.7)	31.5(28.5)	34.3(27.5)
Asian (8)	33.1(27.1)	3.0 (2.5)	38.6(26.7)	30.5(23.9)
Central & S. American (9)	45.6(40.9)	6.8 (4.5)	37.6(27.2)	34.3(28.5)
E. Europe (8)	52.2(47.1)	23.2(16.0)	58.6(49.8)	43.4(36.1)

Notes

(a) Unbracketed figures refer to the years 1969, 1970 or 1971. Bracketed figures refer to the data for the same countries in the years 1959, 1960, 1961 or 1962. The figures for the early 1970's do not agree exactly with those in Table 1 because countries for which data on a given discipline were not available at both dates have been excluded from this Table.

(b) Appendix Table A2 gives the breakdown of the early 1960's figures for each country.

(c) The number of countries in each region is given in brackets after the name of the region.

(d) Data from Unesco Statistical Yearbooks.

There has been some improvement in the position of women in science, and in tertiary education as a whole, over the past ten years. Table 3 compares the percentage of women scientists in the early 1970's with the percentage ten years earlier. Although the changes are not dramatic, in nearly every category there has been a small increase in the percentage of women. But these increases have occurred in all tertiary education, not just in science, and when women's relative representation in natural science is examined over a ten-year period the changes are minimal (Table 4). In the early 1960's, women were relatively under-represented in science in African and Western countries, and relatively over-represented in Central and South American and East European countries; and the same was true of the early 1970's. In Western countries, women's relative representation in natural science decreased over this period from .86 to .75. Women's relative representation in engineering does seem to have increased slightly between 1960 and 1970, whereas the situation in medicine varies from region to region. But the picture is one of basic stability, with changes in science similar to changes in tertiary education as a whole.

This summary of international statistical data illustrates several different aspects of women's position in science. Table 1 shows that women scientists are few in many regions of the world. This shortage is most acute in Africa, but it is also apparent in Arab, Western and Asian countries. The position of women in science is closely linked to the position of women in society,

Table 4. Comparison of the relative representation of women in science-based disciplines in the early 1970's and the early 1960's.

	natural science	engineering	medicine
African	.76(.85)	.04(.01)	1.37(.87)
Arab	1.06(1.03)	.26(.23)	1.35(1.91)
Western	.75(.86)	.12(.10)	.92(1.04)
Asian	1.09(1.13)	.10(.10)	1.27(1.12)
Central & S. American	1.33(1.44)	.20(.16)	1.10(.95)
East European	1.20(1.30)	.53(.44)	1.35(1.38)

Notes

(a) The figures are: $\frac{\text{Percentage of women students in the discipline}}{\text{Percentage of women students in all tertiary education.}}$

(b) Unbracketed figures refer to the years 1969, 1970, or 1971.
Bracketed figures refer to the years 1959, 1960, 1961, or 1962

(c) This Table is derived from Table 3.

and Tables 3 and 4 show that as women's position in education improves, so too does their representation in science. However in Western and African countries women are finding science less attractive than other subjects (Table 2) and it is with these countries, where there is a special problem in science, that this chapter is primarily concerned.

19.3 EMPLOYMENT AND PRODUCTIVITY

Information on the employment and productivity of women physicists is scarce. The American Physical Society (APS) has produced a detailed report [1] on the position of women physicists in the United States and, in the absence of comparative data for other countries, the American figures must serve to indicate the employment situation of women physicists in the Western world. (Appendix Tables A3, A4 and A5 show what scant data is available from other countries). The APS report deals with the distribution of women physicists by field, by qualification and by type of employer, and includes information on salaries and academic rank, although not on productivity. Some of the relevant statistics are shown in Table 5.

Table 5a shows that a much lower percentage of women than men physicists have a Ph.D. degree. Tables 5b and 5c show that women physicists employed in education in the United States are concentrated in less prestigious institutions and in lower ranking posts. Figures from other countries also show women concentrated in lower ranking posts (Tables A3, A4 and A5). Table 5d indicates that women are more often found in educational institutions and less often in industry than men physicists. Census data on the employment of women scientists in the United Kingdom show exactly the same trends [15], and data from the Institute of Physics in the U.K. give a similar picture (Table A3). Table 5e shows the median salaries of women physicists, compared to the median salaries of all physicists in the U.S.A. In every case the women's median

Table 5. The employment characteristics of women physicists in the USA

(a) Highest qualification of women and men physicists

	All physicists		Employed in educational institutions	
	Women (%)	Men (%)	Women (%)	Men (%)
PhD	25.6	46.5	30.5	54.9
MA/MSc	47.4	33.1	50.4	31.7
Other	27.0	20.1	19.1	13.0

(b) Percentage of the staff of physics departments in different types of college and university who are women

	Percentage of women
'Top Ten' universities	0.9
Universities	1.7
Four year colleges with MA/MSc programmes	2.5
Four year colleges with undergraduate programmes only	6.0

(c) Percentage of posts of different academic rank held by women

	Percentage of women
Professor	2.2
Associate Professor	2.7
Assistant Professor	3.2
Lesser Rank	7.4

(d) Percentage of women and men physicists employed in different organizations

	Women (%)	Men (%)
Educational institutions	58	49
Government	8	11
Non-profit organizations	3	2
Industry	9	28
Others	22	9

(e) Ratio of median women physicists salary to median salary of all physicists by qualification level and type of employer

	PhD	MA/MSc	Other
Educational institutions	.90	.87	.83
Government	.93	.90	.85
Non-profit organization	.68	.95	.83
Industry	.92	.84	.77

Note

(a) Data from APS [1].

salary is lower, ranging from .68 to .95 of the overall median. Again the situation in the United Kingdom (Table A3) is similar.

Does this really represent discrimination? Many of the women surveyed by the APS felt that they had experienced discrimination, but the authors of the report comment that they seemed 'more frustrated by their inability to establish conclusive proof of discrimination . . . . than by the discriminatory action itself'. Burrage [6] reported similar feelings among British university women scientists. The higher proportion of men in management positions accounted for some of the salary differential shown in Table 5e. But even when compared by primary work activity [2], women physicists were paid less than men.

There is a further related problem. In responding to the APS questionnaire, women without Ph.D's gave family responsibilities and lack of financial support as the main reasons for not continuing their education. To the extent that family responsibilities fall heavily on women, women are disadvantaged. Lacking a doctorate, they will not be considered for more prestigious appointments, and so a vicious circle is set up. The problems facing women physicists are exacerbated by working conditions which provide little in the way of maternity/paternity leave, day nurseries or retraining opportunities. If women interrupt their careers to raise a family, their knowledge will become outdated; without adequate retraining courses it is difficult to re-enter physics after a break. There is a pressing need for part-time positions (possibly split appointments) which carry prestige, security and professional salaries and which can form an integral part of a developing career. Many able women physicists would take advantage of such opportunities. In the APS survey, 50 per cent of the women who broke their careers said that they would have worked continuously if part-time work had been available; 46 per cent said they would have worked continuously if child care had been available. The problem of independent mobility vis-a-vis their husbands arises but can only be resolved within individual marriages. Anti-nepotism rules, a further problem for women, could and should be replaced so that women can take positions in the same institutions as their husbands.

In contrast to the APS survey, a study of a matched sample of American male and female chemistry, biology and psychology graduates [7] found little evidence of discrimination. There was some clustering of women in low level posts and less prestigious institutions; but when controlled for quality and quantity of research output (measured by number of citations and publications) women and men were evenly distributed through different types of institution. Women still tended to occupy lower-ranking posts, but the authors concluded that women were not discriminated against when judged by science's own criteria of citations and publications.

Research results on the productivity of women scientists are scarce and contradictory. Cole & Cole find that women, particularly married women with children, produce fewer papers than men. But Simon and others [20] find the opposite, with married women producing more than men. Harmon's work, quoted by Kistiakowsky [16], shows that women, particularly married women with Ph.D's in science obtained better scores in high-school ability tests than similarly qualified men. Women are highly pre-selected, both in terms of ability and determination, before obtaining a doctorate. A married woman's decision to work is almost always revocable as there is an alternative role open to her; if and when her work reaches a sticky patch this alternative may be a strong temptation. So married women who stay in science are unusually determined. On the other hand, a woman's prestige and worth is not measured by her success in a career to the same extent as a man's. For this reason women may put less effort than men into producing research papers – the outward symbols of success. This is obviously a complicated topic, and no clear conclusions can be drawn on the existence or interpretation of sex differences in productivity.

The APS survey refutes the suggestion that there is a large wastage factor in training women. At least 80 per cent of women with Ph.D's in physics continue working in physics. British figures, albeit at a lower level of qualification, indicate that 64 per cent of women with B.Sc. degrees in science are currently employed [15]. However even this slightly lower figures does not suggest a great waste of training.

Information from East European countries indicates a varied situation there. Dodge reports that in the Soviet Union women comprise 21 per cent of the university staff in mathematics and physics [11]. Although this compares very favourably with the 4 per cent of physics staff in the USA, women in the USSR still face some of the same problems as do women in the West, particularly concerning domestic responsibilities. But the greatest contrast between East and West is illustrated by Souter and Winslade [21] in their study of women engineers in the USSR. They found that women engineers were so completely accepted that questions about women's ability in engineering were not understood in the USSR. This acceptance is probably the most important factor encouraging girls into science and engineering.

19.4 ACCEPTABILITY OF WOMEN IN PHYSICS

An attempt has been made to determine the extent to which girls are accepted in physics in different countries; this was done by means of a questionnaire. The samples were small and not statistically representative, so the results are only suggestive. However, they do show a wide variation from country to country. Table 6(a) shows the way pupils respond to the question

Table 6. Responses to questionnaire on girls and physics

(a) The percentage of boys and girls in different countries who chose each answer to the question on suitability of physics (see text)

	Boys (%)			Girls (%)			Numbers	
	(a)	(b)	(c)	(a)	(b)	(c)	Boys	Girls
Brazil	0	0	100	0	1	99	72	83
Federal Republic of Germany	4	57	39	0	46	54	80	58
N. Ireland	6	60	34	0	12	88	48	27
Italy	0	13	87	0	4	96	53	74
Swaziland	0	57	43	0	8	92	32	12
Thailand	0	25	75	3	24	73	20	98
Trinidad & Tobago	0	43	58	0	23	76	234	201
U.S.A.	0	18	82	0	8	92	56	25

(b) Relationship between the percentage of science students who are women (see Table A1) and the percentage of respondents choosing answer (c).

	Women scientists (%)	Answer (c) (%)	
		Boys	Girls
Federal Republic of Germany	20	39	54
Trinidad & Tobago	33	58	76
Italy	39	87	96
Thailand	41	75	73
Brazil	48	100	99

'Do you think physics is (a) more suitable for girls, (b) more suitable for boys, (c) equally suitable for girls and boys?'. The percentage of respondents choosing answer (c) ranges from 100 per cent of boys in Brazil to only 34 per cent of boys in N. Ireland, presumably reflecting cultural differences in the acceptability of women in physics. It is noticeable that in most countries girls were more likely than boys to choose answer (c).

Table 6(b) shows that for the five countries where a comparison is possible, there is a strong relationship between the percentage of pupils choosing the egalitarian answer (c) and the percentage of women scientists. The effect is probably two-way: where it is accepted that physics is suitable for girls, women are more likely to become scientists; and where a large percentage of scientists are women, physics is more likely to be thought suitable for girls. This pilot study suggests that a thorough investigation of attitudes towards women in physics would yield important information about the reasons why women in the West tend to avoid physics.

19.5 GIRLS AND PHYSICS EDUCATION

19.5.1 Girls' performance in physics

Evidence on the relative attainment of girls and boys in physics comes from the IEA study *Science Education in Nineteen Countries* [8] and a study by Hnilickova in Eastern Europe [13]. In general, boys perform better than girls in physics tests. Table 7 shows the mean difference between girls and boys scores in three age groups – ten year olds, fourteen year olds and pre-university. The sex differences are highly significant (beyond the 0.1 per cent level) and are larger in the older age groups. All pupils (not just those studying science) were tested, so it may be that some of the difference in the pre-university group is due to more girls having ceased the study of physics.

Table 7. Mean differences between girls and boys scores in physics attainment tests administered to ten-year-olds, fourteen-year-olds and pre-university school pupils.

	ten-year-olds	fourteen-year-olds	pre-university
Western (14)	45	61	90
Asian (3)	15	26	21
South American (1)	26	46	43
East European (4)	37	35	78

Notes

(a) Appendix Table A6 gives the breakdown for each country

(b) The number of countries in each region is given in brackets after the name of the region

(c) Data from Comber & Keeves [8] and Hnilicková [13]

(d) The sex differences are given in standardized form, as percentages of the mean standard deviation of scores.

Since most of the countries for which complete data on attainment are available are in the Western category, comparisons between regions of the world are unreliable. However, the figures do suggest that the sex differences are larger in Western countries than elsewhere. This may reflect the relative importance of science learning in and out of school. In technological societies, such as those of the Western countries, much science learning takes place informally out of school. Boys may have greater access (through toys and household tasks) to this informal learning. But in non-technological societies, such as those of Asia and South America, nearly all science is learnt in school; girls receive as much instruction as boys, so reducing the sex difference in exposure to science. It is noticeable that the absolute level of science attainment (not shown here) is much lower in the non-technical societies, possibly because informal science learning is absent. Data on Eastern Europe comes mainly from Hnilickova's study (which used different tests from the IEA study) and so it is not possible to compare the absolute levels of attainment. The smaller sex difference in Eastern Europe probably reflects the more egalitarian expectations in those countries. The Soviet Union was not included in these studies but Souter and Winslade [21] report that there is no sex difference in attainment there.

There has not been a thorough attempt to account for these sex differences in attainment, but some hints do exist. Hnilickova [13] suggests that 'the less successful results scored by girls in physics are relatable not so much to their aptitude as to the fact that they are generally less interested in physics'. The same seems to be true in the West. The IEA survey measured interest in science by questions on the frequency of children's science-related activities, their self-reported interest in science and their view of science in the world. In all countries where this test was used, boys were more interested than girls in science. (These were all Western countries and the results of the test are only reported for the fourteen-year-olds and pre-university pupils.) This result may go some way to providing an explanation for the sex difference in physics attainment. If girls are not interested in physics they are unlikely to put much effort into studying it and will probably perform poorly in physics attainment tests. This survey did not measure interest in physics, chemistry and biology separately, but several studies have shown girls to be most interested in biology and least interested in physics. The IEA survey found sex differences in attainment to be small in biology, intermediate in chemistry and large in physics. Thus attainment and interest in studying a science appear to be related. While it is possible that poor performance causes lack of interest, in the absence of any evidence it is more optimistic to assume that if girls' interest in physics could be improved, their attainment would also increase.

19.5.2 Textbooks

Girls may lose interest in physics because such interest is not expected of them. Children are highly conformist and if physics is seen as a subject for boys, girls are unwilling to become involved in it. However, if they can see that women are accepted and welcomed in physics, girls will be better motivated. One way of investigating the acceptability of women in physics is to study school textbooks and the biases they contain. Textbook writers reflect, probably unconsciously, the general opinion about women's place in society. But they also convey to the pupils who read these books an impression of what is expected in physics. This impression is most important in the first few years of secondary school, when pupils are still undecided about whether they wish to continue studying physics.

Table 8 gives the results of a survey of three sets of pupils' books used in the first two or three years of secondary schools in the U.K. The textbooks are all modern in approach and obviously try to appeal to pupils' imagination and curiosity. Yet the preponderance of items – questions, problems, drawings and photographs – representing boys or men is marked. Although only three books have been surveyed, the working group took them as representative of English-language textbooks. Members of the conference from other parts of the world, however, did not have the same impression of their textbooks. In Scandinavia, books in all subjects are carefully checked

Table 8. The number of representations of males and females in three sets of physics textbooks which are used in the first few years of United Kingdom Secondary schools.

Book	Material considered	Activity represented	Boys or men only	Girls or women only	Both/either/ indeterminate sex	Comments
Nuffield Physics Pupil's Question Books I, II & III	Questions and problems	Experimenting	75*	0	7	'Freddie Jones' and 'Uncle George' are used to represent a typical pupil and a typical intelligent layman.
		Examples and illustrations from everyday life	52	3	13	*25 of these experiments concern 'Freddie' or 'Tommy'. The rest are mainly numerical problems. The questions are mainly written in a direct form ('you . . . . .') or in the passive tense, and so do not indicate sex. 'Indeterminate' includes 'scientist' 'a driver' 'a person' 'some pupils' etc. If identified as male, these references are included in the 'men only' category.
Physics is Fun, Books I & II	Drawings	Experimenting	65	20	2	
		Examples and illustrations from everyday life	29	0	0	
Science for the 70's Books I & II	Drawings and photographs	Experimenting	22	8	3	This is an integrated science textbook, and so covers biology and chemistry (subjects in which girls are more frequently represented) as well as physics.
		Examples and illustrations from everyday life	24	5	11	Illustrations of factories, cars etc. (i.e. situations and objects usually associated with men) have not been counted unless a person is also illustrated.

and any sex bias removed before publication. The following remarks apply specifically to English language texts.

To a certain extent this preponderance of male items may reflect the conventions of the English language, but this excuse is not valid for drawings nor for questions involving 'Freddie Jones', 'Uncle George' or 'a boy'. Writers may well object that it is clumsy to write 'he or she', but it would make a refreshing change to have 'Susie Brown' explaining some physics to 'Aunty Mary' or to read occasionally 'a scientist . . . . she . . . .'. The first reaction by pupils to such a sentence would probably be 'How do you know the scientist was a woman?', so disrupting the lesson and diverting attention from the physics of the question. But such reactions would not persist if the scientists were frequently 'she', and any disruption is a small price to pay for encouraging pupils, of both sexes, to see women in physics as commonplace.

Books can give the clear impression that physics is done by and for men. The sparseness of examples of physics-related activities from women's lives is very striking. It would not be difficult to incorporate such examples. Even an entirely traditional view of women's lives could involve air pressure (vacuum cleaners), heat transfer (cooking, domestic heating), electric circuitry (domestic wiring), density (shopping), and energy changes (almost anything). The list could be continued almost indefinitely. A textbook should show both sexes participating equally in experimental, industrial and domestic situations involving physics. The physics community can act directly to encourage girls by rewriting the textbooks so that girls feel that they belong in physics and that physics will have some relevance to their future lives. There are two ways of doing this. One is to emphasise 'kitchen physics' i.e. to show how physics affects the domestic life that many girls have come to expect; the other is to broaden girls' horizons by showing women in physics-related occupations from nuclear scientist to machine-tool operator. These two aspects are not necessarily in conflict, but can and should complement each other. 'Kitchen physics' involving boys is the other side of the coin to 'factory physics' involving girls and should also be included. Existing textbooks may possibly discourage girls from studying physics.

19.5.3 Syllabuses

What of the syllabuses themselves? Are they more suitable for boys than for girls? The evidence is indirect, but suggests that they are.

Girls like subjects in which they can use their imagination and express their own opinions. Most physicists would say that this is possible – indeed essential – in physics. But to early secondary school pupils, physics appears to be a cut-and-dried subject, in which all the answers are already known and in which imagination and personal opinions are out of place. Most syllabuses make some reference to social implications but this is not a central part of the course and may well be omitted when time runs short. Yet Ormerod [17] has shown that girls' attitudes towards science as a force for good in the world correlate strongly with their choosing to continue studying science (his more recent work [18] shows a similar effect for boys). Of course correlation does not imply causation, but it seems likely that if more attention were paid to the social implications of science in the first few years of secondary school, pupils (girls as well as boys) would react favourably and would be more willing to continue studying science.

It would not be difficult to design a science course based on the social implications of science, a topic discussed in more detail in another chapter. Physics would appear almost as a by-product of such a course. For example, in a study of the hazards of nuclear power it would be necessary to understand why waste material must be kept safe for millions of years; in a study of communication the principle of the telephone and radio would be explained. Old favourites such as the eye, the vacuum flask and X-rays would still have their place, but as part of the topics 'science and our bodies', 'science in the home', and 'science in the hospital' rather than 'light', 'heat' and 'modern physics'. By relating physics to girls' knowledge and background, such a course might improve their attitudes towards physics. Even if it did not result in more physics specialists, such a course in the first few years of secondary school would be more suitable for pupils (of both sexes) whose physics would be limited to a nodding acquaintance with the principle of moments or the specific heat of copper.

Less fundamental syllabus changes might also encourage girls. One of the most consistent comments that pupils make about physics is that it is difficult. Difficulty can be expressed within a Piagetian framework in terms of concept development. For several reasons, undue difficulty may have more serious consequences for girls than for boys. Girls are generally more re-inforceable than boys, more encouraged by success and more discouraged by failure. Where boys see difficulty as a challenge, girls are more likely to be worried by their failure to understand and to retreat from the difficulty by dropping the subject. In general, girls enter secondary school with less interest and less background knowledge in physics than do boys, so they have less to fall back on if the classwork is beyond them. In Shayer's words [19] the effect of trying 'to make someone participate in a process which is taking place at a more complex level than that to which they have access . . . . is unmistakable, as of the floor having given way without warning. In girls, particularly, it can cause either acute anxiety or resentment or both'.

A rather different approach comes from the United States, where Bridgham has worked for some years on the effects of severe grading practices in the sciences. He found that pupils tended to get lower grades in their science subjects than in non-science subjects and that this effect was more marked for girls than for boys. Although the girls taking science did as well as the boys in science, they did better than the boys in non-science subjects and so the differential between their science and non-science marks was larger. In a pilot study (which did not separate the sexes) Bridgham and Welch [5] showed that the pupils of teachers who gave high grades in physics were significantly more likely to wish to take another physics course than were pupils of teachers who gave low grades (controlling for objective level of performance). The subsequent study [4] used a regression analysis and suggested that if science grades were no more severe than grades in other subjects, girls' enrolments in physics would increase by 80 per cent. The effect for boys was negligible. A regression analysis is not as convincing as an experimental demonstration, and the same effect might be produced by the sex difference in attitude towards science. But this result does support the hypothesis that girls are encouraged by success and discouraged by failure, and that more girls would study physics if it were not seen as a difficult subject. It should be emphasized that both boys and girls find physics difficult, the difference between them being that girls are more discouraged by the difficulty.

However, the whole philosophy of modern courses with their emphasis on discovery methods and experimental work may be more suitable for boys than for girls. Harding, in her work on the Nuffield curriculum diffusion project, found many teachers complaining that 'girls can't operate the Nuffield approach like boys can', and this was reflected in the O-level results [12]. Although on traditional syllabuses girls' results were as good as those of boys at O-level, boys did much better than girls on the Nuffield syllabus. And this was not because more girls of lower average ability were entering for Nuffield, if anything the opposite was true. The discovery approach just does not seem to suit many girls whose learning style is better suited to more highly structured tasks and the verbal, descriptive aspects of science. This was confirmed in an American study by Babikian in 1971 in which expository, laboratory and discovery methods of teaching Archimedes' Principle were compared [3]. Boys with high IQ learnt equally well by any method, but whereas girls with high IQ did almost as well as the boys with the expository and laboratory methods, they achieved much less well with discovery methods. It is interesting that even in the Soviet Union teachers report sex differences in learning style. Girls are 'more conscientious, diligent and persevering than boys: they are more even and systematic in their studies, while boys have ups and downs' [21]. Similar reports are common in the United Kingdom and the U.S.A. Such persistent sex differences should not be ignored in designing physics syllabuses.

There are two factors in syllabus design which must be carefully balanced. One is to broaden pupils' horizons by introducing them to experiences and modes of thought they may not have met previously. The other is to retain their interest and attention by presenting the sort of situation they can grasp and enjoy. Many physicists feel that only discovery methods can do justice to physics, but unfortunately this has the effect of turning many girls in the thirteen to sixteen age group away from physics. Perhaps this is because they are reaching puberty and so are particularly vulnerable to social forces. Whatever the reason, if girls abandon physics during this time they are unlikely, and often unable, to take it up again later on. Hence, it is important to retain their interest over this period, perhaps by different approaches to physics teaching. Project Physics has attempted to do this by placing physics in its cultural context. Art, history, philosophy, music and technology are included with physics, but this does not lessen the validity of the physics being taught. The rationale for this varied approach is that if you want to communicate you must talk in a language your audience understands. The whole scheme is presented in a flexible form so that pupils can pick out the aspects of physics which interest them. One result has been that an estimated 35–40 per cent of the pupils enrolled in the course in the United States are girls (compared to less than 10 per cent nationwide). This success shows that it is not impossible to design physics syllabuses which appeal to girls.

Clearly any difference between boys' and girls' learning styles are group differences, and individuals do not all fit the group pattern. To accommodate these individual differences, a range of teaching styles is appropriate so that each pupil can choose the approach, be it verbal or experimental, expository or discovery, best suited to his or her learning style.

19.5.4 Schools

In many parts of the world there is a movement away from single-sex schools and towards co-education. However, there is relatively little information on how this affects attainment in physics or in any other subject. At first sight it might appear that co-education would benefit girls because girls' schools have generally had poorer laboratory facilities and a greater shortage of science teachers than other schools. Where resources are limited they have tended to go to boys and co-education should mean that girls get a fairer share of the resources.

However, the situation is not as clear cut as this. The IEA survey of Science Education in Nineteen Countries included information on whether the children were in single-sex or co-educational schools. The results varied from country to country and they are not easy to interpret (partly because in some countries one type of school may be more prestigious or academic than the other). But overall the difference between the sexes in attainment was similar at co-educational and single-sex schools. Three British studies, concentrating not on attainment but on attitudes towards physics [9] or on numbers continuing to study physics [10], [18] have shown that girls in single-sex schools are more favourably disposed towards physics than girls in co-educational schools. This is true even when the academic level of the school is taken into account, that is when single-sex grammar schools are compared with co-educational grammar schools. Probably the reason is that in a girls-only school there is not such a strong tendency for physics to be labelled as a boys subject. Also the physics teacher in a girls' school will have to pay closer attention to the specific interests and abilities of the girl pupils than if they were in a mixed class. These factors appear to compensate for poor facilities and lack of staff. Incidentally, the effect on boys is opposite – they study more physics in co-educational schools; and in language subjects the reverse situation occurs – boys study more languages in boys-only schools, whereas girls study more languages in co-educational schools. This emphasizes the point that sex-typing (science for boys, languages for girls) is stronger in co-educational schools.

The sex of the teacher probably affects girls' attitudes towards physics, but it is not a topic that has been much studied. There are two main schools of thought: that girls will be attracted into physics by a male teacher or that contact with a woman physicist will encourage girls by demonstrating that women can do physics. The preliminary results from the IEA survey are in favour of male teachers, but the analysis was not done separately for girl and boy pupils and there might be an interaction effect, by which men teachers are better for boys and women teachers for girls. Women physics teachers are more common in girls' schools and may contribute to the higher proportion of girls studying physics in these schools. This is an interesting and important question, but it is still unanswered.

19.6 CONCLUSION

In discussion of this topic at the Edinburgh conference, those from Western countries felt strongly that changes in physics courses would only be marginally effective unless accompanied by more fundamental changes in society. Nevertheless even marginal improvements are worthwhile and we should not be discouraged by these wider issues or by the inertia of society from doing what we can in physics itself.

Physics has an image created by the media as well as the schools of being remote, difficult and eccentric. Dodge [11] explains how, when the USSR wished to industrialize rapidly and so needed a greatly increased supply of scientists in a short time, conscious efforts were made to improve the image of the scientist. The scientist was portrayed as the hero in films and books. Young people were encouraged to visit industrial plants and work in industry before completing their studies, so as to form a clear idea of the scientists' work and way of life. Perhaps similar methods could be used to destroy the masculine image of physics in the West. As the international comparisons show, where women are not handicapped by stereotyped expectations they can, and do, study physics successfully.

The details given in this chapter are based on published studies of women in physics education mainly conducted in the English-speaking countries of the Western world. Unfortunately, little is known about the physics education of women in developing countries; perhaps an international agency such as Unesco should undertake a systematic investigation. The problems of women scientists in both developed and developing countries stem from their cultural, social and economic backgrounds. An exchange programme of women physicists between developed and developing countries might provide useful encouragement to girl physics students in developing countries.

Various recommendations have been made in this chapter – recommendations concerning the gathering of information, the structure of courses, and the content of illustrations.

19.7 REFERENCES AND BIBLIOGRAPHY

1. American Physical Society, report of the Committee on Women in Physics, *Bulletin of the American Physical Society*, II, *17*, 740, 1972.
2. Ancker-Johnson, Betsy, Women's Lib and Physics, *The Physics Teacher 10*, 599, 1972.
3. Babikian, Yeghia. An Empirical Investigation to Determine the Relative Effectiveness of Discovery, Laboratory and Expository Methods of Teaching Science Concepts, *J. of Research in Science Teaching*, *8*, (3), 201, 1971.

4. Bridgham, Robert. Ease of Grading and Enrolments in Secondary School Science, *J. of Research in Science Teaching 9*, (4), 323, 1972.

5. Bridgham, Robert and Welch, Wayne W. Physics Enrolments and Grading Practices. *J. of Research in Science Teaching, 6*, (1), 44, 1969.

6. Burrage, Hilary. An Investigation of the Social Situation of Women University Teachers of Natural Science. M.Sc. Dissertation, University of Salford, 1973.

7. Cole, J.R. and Cole, S. *Social Stratification in Science*, Chapter 5, University of Chicago Press, 1973.

8. Comber, L.C. and Keeves, J.P. *Science Education in Nineteen Countries*, IEA Report, Wiley, 1973.

9. Dale, R.R. *Mixed or Single-sex School? Vol. III: Attainment, Attitudes and Overview*. Routledge & Kegan Paul, 1974.

10. Department of Education and Science. Curricular Differences for Boys and Girls. *Education Survey 21*. HMSO, 1975.

11. Dodge, N.T. *Women in the Soviet Economy*. Johns Hopkins Press, 1966.

12. Harding, J. What has Nuffield Done for Girls? *Times Educational Supplement*, 30.11.73.

13. Hnilickova – Fenclova Jitka, Pedagogicka Fakulta, Prague University: Differences in the Knowledge of Physics between boys and girls. Private Communication 1975.

14. Keeves, J. Differences between the Sexes in Mathematics and Science courses, *International Review of Education 19*, 47, 1973.

15. Kelly, Alison. *A Discouraging Process: How Women are eased out of Science*. Paper presented at a conference on Girls and Science Education, Chelsea College, London, March 1975.

16. Kistiakowsky, Vera. *Women in Engineering, Medicine and Science*. Paper presented at a conference on Women in Science and Engineering, National Research Council (USA), June 1973.

17. Ormerod, M.B. The "Social Implications" Factor in Attitudes to Science, *British Journal of Educational Psychology, 41*, 335, 1971.

18. Ormerod, M.B. *Science Education: Attitudes, Subject Preference and Choice*, Paper presented at a conference on Girls and Science Education, Chelsea College, London, March 1975.

19. Shayer, M. Conceptual Demands in the Nuffield O-level Physics Course. *School Science Review 53*, 26, 1972.

20. Simon Rita James, Clark Shirly Merrit & Galway Kathleen. The Woman PhD: A Recent Profile, *Social Problems 15*, 221, 1967.

21. Souter, L.S. and Winslade, R. *Women Engineers in the USSR*. Caroline Haslett Memorial Trust, 1960.

22. UNESCO. *Statistical Yearbooks*. 1964–1970.

23. White, Martha S. Psychological and Social Barriers to Women in Science. *Science 170*, 413, 1970.

In addition to the references given above, the following two reviews of women in science both contain extensive bibliographies. Support for unreferenced statements in the present chapter will be found in these reviews.

24. Gardner, P.L. Sex Differences in Achievement, Attitudes and Personality of Science Students: A Review. To be published in *Science Education:* Research 1974.

25. Kelly, Alison. Women in Science: A Bibliographic Review. To be published in *Durham Research Review*, 1976.

The following books and articles deal with aspects of women's involvement in science which have not been discussed here:

26. Feldman, Jacqueline. The savant and the midwife. *Impact of Science on Society 25*, (2), 125, 1975.

    A feminist analysis of the structure of science and woman's place in that structure. Shows how women have been excluded and suggests ways in which a new science should develop.

27. Maccoby, E.E. Feminine Intellect and the Demands of Science. *Impact of Science on Society, 20*, (1), 13, 1970.

Identifies the intellectual characteristics needed for science and shows how these are fostered by child-rearing practices stressing independence and dominance. These characteristics are accepted and encouraged in boys, but are often discouraged in girls. Girls who are aggressive frequently experience anxiety which then inhibits their creativity.

28. Roe, Anne. *The Making of a Scientist,* New York 1952.

A classic study of the personality patterns of eminent scientists. Only men are considered, but this book is important for two reasons. It shows how uninterested in people some eminent scientists are. And it illustrates the long hours and dedication necessary to reach the top. This type of commitment is more easily achieved if a 'wife figure' is available to provide back-up.

29. Rossi, Alice. Barriers to the Career Choice of Engineering, Medicine or Science among American Women in *Women and the Scientific Professions* (ed) Mattfeld & Van Aken, M.I.T. Symposium, 1965.

Survey of women college graduates attitudes towards scientific careers. They consider that careers in engineering would be unfeminine, discouraged by their parents, resented by their male colleagues and would require skills which women do not possess. Science and medicine are viewed more favourably, but are seen as too demanding to combine with family life, and as offering too few opportunities for part-time work. Men are, in general, more conservative about women's careers than are women, but men are not as conservative as women think they are.

30. Schilling, Gerhard F. & Hunt, Kathleen. *Women in Science and Technology: US/USSR Comparisons,* p. 5239 Rand Corporation, Santa Monica, California June 1974.

A few comparative facts and figures. The difference between the two countries is characterized as 'US women want participation in the economy whereas the USSR economy needs women's participation'. Envisages a narrowing of the gap between the two countries in the utilisation of women scientists. Ideological difference relating to women's position are according only a minor role.

31. Walberg, H.J. Physics, femininity and creativity. *Developmental Psychology 1,* 47, 1969.

Suggests that girls do relatively well in school physics because they are verbal, docile and will work for their teacher's approval. But scientific creativity requires autonomy, self-sufficiency and high spatial ability, which girls do not possess. Seems to see both physics and femininity as immutable, and basically in conflict.

19.8 APPENDICES

Table A1. The number of women students (at the tertiary level) in natural science, engineering, medicine and all subjects, expressed as a percentage of the total number of students in these disciplines in various countries, in the early 1970's.

	Percentage of women			
	natural science	engineering	medicine	all tertiary
African				
Zaire (71)	2.8	3.0	9.1	6.5
Congo (70)	4.2	–	–	4.9
Togo (71)	4.7	–	–	11.2
Ethopia (71)	5.6	0.6	7.9	7.5
Cameroon (71)	7.5	–	12.1	9.2
Ghana (71)	8.0	0.0	21.0	13.7
Senegal (71)	9.5	5.0	23.9	15.9
Tanzania (71)	10.7	–	10.3	17.6
Ivory Coast (71)	12.0	–	17.4	14.7

Table A1 (continued)

	Percentage of women			
	natural science	engineering	medicine	all tertiary
African – continued				
Zambia (70)	12.9	0.0	–	14.8
Uganda (71)	14.5	–	15.0	19.1
Nigeria (70)	15.3	1.0	18.0	14.2
Malawi (71)	16.1	0.0	–	17.1
Arab				
Saudi Arabia (71)	0.0	0.0	0.0	10.2
Sudan (71)	8.8	1.5	16.5	14.6
Morocco (71)	16.6	1.2	20.2	16.5
Syria (71)	19.0	5.1	18.3	18.8
Lebanon (69)	19.9	0.9	32.9	23.1
Libya (71)	22.0	6.0	16.3	11.7
Algeria (71)	24.2	2.8	25.9	22.8
Jordan (71)	29.1	0.0	94.2	31.6
Iraq (71)	31.2	7.9	25.5	21.6
Egypt (71)	34.4	9.6	27.2	27.0
Kuwait (71)	43.3	–	–	49.1
Western				
Japan (71)	12.8	0.9	41.0	28.1
Iceland (71)	13.1	4.4	12.4	26.5
Netherlands (71)	14.6	6.6	22.2	28.2
Norway (70)	16.0	3.1	38.7	30.2
Switzerland (71)	19.5	2.1	21.1	23.7
Federal Republic of Germany (71)	20.1	2.3	25.9	28.5
Australia (70)	20.1	0.7	34.8	32.7
Greece (71)	20.4	6.0	28.9	32.8
Austria (71)	21.1	5.0	30.2	31.9
England and Wales (69)	21.6	1.6	31.3	39.2
New Zealand (71)	21.9	0.9	20.4	40.5
Denmark (70)	22.0	3.1	37.7	36.7
Sweden (71)	22.2	8.3	41.0	41.6
Canada (71)	22.5	1.8	47.7	36.1
Scotland (69)	23.2	1.4	29.4	31.2
Turkey (71)	25.1	7.6	34.1	19.2
Spain (71)	31.3	1.3	28.7	28.1
Belgium (71)	35.2	2.7	29.4	29.5
Israel (70)	38.7	4.6	28.1	48.3
Italy (71)	38.8	1.1	21.6	37.6
Finland (71)	41.0	6.0	43.1	48.2
Portugal (71)	49.2	14.4	48.2	46.2
Asian				
Bangladesh (70)	7.5	0.2	19.1	9.7
Nepal (69)	13.6	–	–	18.2
Afghanistan (70)	15.1	1.9	26.0	14.8
Pakistan (70)	16.0	0.4	23.9	18.9

Table A1 (continued)

	Percentage of women			
	natural science	engineering	medicine	all tertiary
Asian — continued				
Hong Kong (71)	17.8	1.0	16.5	27.8
Cambodia (71)	24.8	11.1	22.3	21.2
Republic of S. Vietnam (69)	25.0	0.8	40.7	29.0
Malaysia (71)	25.0	7.0	18.0	30.0
Sri Lanka (70)	31.7	5.4	37.3	43.3
Indonesia (71)	32.3	7.3	32.5	27.5
Iran (71)	33.0	10.1	36.5	29.7
Singapore (71)	38.6	6.6	28.0	31.3
Thailand (71)	40.9	1.5	50.9	41.3
Korea (71)	47.4	0.9	50.6	24.8
Phillipines (69)	60.5	5.3	81.0	55.0
Central and South American				
Guyana (71)	22.2	1.7	—	23.0
Chile (70)	31.4	5.7	60.3	38.4
Trinidad & Tobago (70)	32.9	1.5	—	35.0
Peru (71)	33.2	8.9	50.3	35.3
Martinique (69)	39.2	—	—	35.6
Mexico (69)	40.6	3.2	24.0	18.5
Panama (70)	42.4	4.6	56.4	46.0
Cuba (70)	45.0	19.3	47.9	39.4
Brazil (71)	47.6	4.4	33.9	40.2
Dominica (71)	49.1	9.9	47.4	41.5
Argentina (71)	53.6	5.1	42.4	44.9
Ecuador (70)	56.2	1.8	30.0	30.1
Paraguay (70)	64.1	6.4	54.2	42.1
Guatemala (71)	66.9	2.8	11.7	20.3
East European				
German Dem. Rep. (69)	27.6	12.1	55.8	33.5
Albania (69)	34.5	14.6	38.7	32.4
Czechoslavakia (71)	46.7	14.6	54.8	38.2
Yugoslavia (71)	48.2	16.7	60.1	39.4
Romania (71)	52.2	20.4	62.9	43.0
Hungary (71)	53.9	19.8	55.8	44.2
Poland (71)	60.9	22.1	76.2	47.1
Bulgaria (71)	69.0	39.0	64.4	53.6
USSR (70)	—	38.3	55.8	49.1

Notes

(a) Data from Unesco Statistical Year Book 1973 and/or 1972 Table 4.2

(b) The year to which the data refer is given in brackets after the name of each country.

(c) Countries with less than 1,000 students have been omitted.

(d) Disciplines with less than 100 students or for which figures are not available are marked with a dash.

(e) 'Tertiary education' means all post-secondary or higher-education.

Table A2. The number of women students (at the tertiary level) in natural science, engineering, medicine and all subjects, expressed as a percentage of the total number of students in these disciplines in various countries, in the early 1960's.

	Percentage of women			
	natural science	engineering	medicine	all tertiary
African				
Ethopia (61)	4.7	0.4	–	4.1
Ghana (62)	7.2	0.0	8.0	6.9
Senegal (61)	17.6	–	21.7	18.2
Ivory Coast (62)	19.1	0.0	–	22.4
Uganda (60)	3.6	–	2.8	7.4
Nigeria (61)	4.2	0.0	6.4	7.9
Arab				
Saudi Arabia (60)	0.0	–	–	0.0
Sudan (62)	4.1	0.0	16.0	6.3
Morocco (61)	29.8	0.0	–	15.4
Syria (61)	13.9	7.6	27.2	15.6
Lebanon (59)	12.3	0.2	31.6	23.4
Libya (61)	5.9	3.8	–	3.2
Iraq (61)	28.4	4.2	31.2	22.1
Egypt (60)	12.0	5.1	17.6	17.0
Western				
Japan (61)	13.3	0.7	62.2	22.9
Netherlands (61)	13.0	1.1	20.1	17.7
Norway (60)	17.5	2.0	21.1	20.7
Switzerland (61)	13.0	0.5	18.4	17.4
Fed. Rep. of Germany (61)	12.2	1.5	32.9	23.5
Australia (60)	18.7	1.2	28.3	27.3
Greece (61)	20.9	2.8	23.2	25.9
Austria (61)	27.3	4.1	32.4	23.4
England & Wales (60)	19.8	2.5	23.5	32.5
New Zealand (62)	25.1	1.5	25.2	31.3
Denmark (60)	20.3	4.9	29.5	32.6
Sweden (61)	26.6	4.4	32.6	34.3
Canada (62)	15.2	0.7	38.3	27.0
Scotland (60)	25.2	1.5	25.0	27.2
Turkey (61)	28.5	5.8	22.8	20.8
Spain (60)	22.2	0.3	20.0	18.0
Belgium (61)	24.6	5.7	27.9	27.3
Israel (61)	53.4	5.8	25.0	43.0
Italy (61)	34.2	0.7	19.0	28.7
Finland (61)	35.0	2.7	42.3	47.5
Portugal (60)	35.2	7.4	30.0	29.7

Table A2 (continued)

	Percentage of women			
	natural science	engineering	medicine	all tertiary
Asian				
Pakistan/Bangladesh (61)	6.2	0.0	20.0	12.4
Hong Kong (61)	26.4	3.4	10.9	30.0
Rep. of S. Vietnam (60)	10.4	0.4	29.2	17.7
Sri Lanka (60)	28.5	0.0	16.0	17.0
Indonesia (59)	28.5	4.6	16.9	19.5
Singapore (60)	18.7	–	22.1	23.9
Korea (62)	26.7	1.1	30.8	19.4
Phillipines (60)	71.4	7.8	67.5	51.4
Central & South American				
Chile (60)	29.1	2.5	35.7	36.9
Peru (60)	22.9	3.5	28.0	25.5
Mexico (60)	34.2	1.1	20.9	17.5
Cuba (61)	59.6	13.7	28.4	37.9
Brazil (61)	36.9	1.5	24.4	29.4
Dominica (61)	–	5.9	–	24.4
Argentina (61)	32.0	2.9	30.8	34.2
Ecuador (60)	49.2	2.9	22.4	18.7
Paraguay (60)	63.2	6.3	26.8	31.7
East European				
Albania (60)	22.6	4.2	27.6	16.6
Czechoslovakia (60)	49.4	11.8	55.5	34.1
Yugoslavia (61)	40.0	11.6	42.4	29.5
Romania (62)	50.2	18.1	50.3	35.8
Hungary (61)	53.1	13.6	46.7	53.2
Poland (62)	55.0	12.2	61.6	35.3
Bulgaria (61)	59.2	27.3	57.7	40.9
USSR (60)	–	29.6	56.5	43.5

Notes

(a) Data from Unesco Statistical Year Books.

(b) The year to which the data refer is given in brackets after the name of each country.

(c) Countries with less than 500 students have been omitted.

(d) Disciplines with less than 50 students or for which figures are not available are marked with a dash.

(e) The restrictions on numbers in notes (c) and (d) are less stringent than the corresponding restrictions in Table A1. Ethopia, Ivory Coast, Uganda and Libya have less than 1,000 students and figures for these countries may be misleading. They are included to maintain the number of countries in the African region, which would otherwise be too small to be meaningful.

Table A3. Women physicists in the UK

(a) Percentage of those awarded qualifications in physics in 1971 who were women

	Percentage of women
PhD.	3.6
M.Sc.	9.4
B.Sc. (hons)	12.4
B.Sc. (pass)	13.6
A level	17.6
O level	21.4

(b) Percentage of members of the Institute of Physics who are women

	Percentage of women
Fellows	1.5
Members	2.5
Associate members	6.7
All classes	4.2

(c) Percentage of physicists who are women, by type of employer

	Percentage of women
Industry	2.4
Education (all)	4.0
(university)	2.6
Public	3.6
Unemployed	10.3

(d) Percentage of physicists who are women, by type of work

	Percentage of women
Management, Administrative & Sales	1.7
R. & D., science and technology, production	4.3
Education	5.2

(e) Median salaries of members of the Institute of Physics, by age group

Age group	Median Salary	
	Women members	All members
26–30	2240	2800
31–35	3200	3485
36–40	3390	4010
41–45	3608	4661
46–50	3874	4900

Notes

(a) Data for Table (a) from Statistics of Education 1971, Vol. 2 & 6. Data for Tables (b) to (e) kindly supplied by the Institute of Physics from their 1974 Remuneration Survey.

Table A4. Comparison of the percentage of physics students who are women in various countries.

Country	Percentage of women
Australia	
Undergraduate	20
Graduate	7
Brazil (1975)	
Undergraduate	21
Graduate	35
Czechoslovakia (1974)	
Students for research	21
Student teachers, lower secondary	56
Student teachers, upper secondary	67
Egypt	
Undergraduate	30
Graduate	6
Fed. Rep. of Germany (1970)	
Students	5
Hungary	
Students for research	10
Student teachers	66
Italy	
Students	30
Malaysia	
Undergraduate	20
Graduate	0
Nigeria (1966–74)	
Graduates	14
Poland	
Students	40
Swaziland (1971–74)	
Students	0
Sweden	
School	35
Undergraduate	15
Graduate	5
U.K. (1971)	
First year undergraduates	14
Graduates	7
U.S.A. (1973)	
Undergraduate	6
Masters	6
Doctorate	4
West Indies	
Undergraduate (first year)	50
Undergraduate (final year)	20

Notes

(a) Data from personal contacts in the various countries. Where the name of the country is not followed by a date, the information was estimated by conference participants.

(b) Graduate refers to post-graduate (PhD) students.

Table A5. Comparison of the percentage of employed physicists who are women in various countries.

Country	Percentage of women
Brazil (1974)	
Professor	0
Associate Professor	12
Assistant Professor	24
Czechoslovakia (1973)	
Prague & Brno universities:	
Professor	0
Reader	10
Assistant	19
France (1974)	
French Physical Society	10
Hungary	
Professor	10
University Staff	15
Staff of Research Institute	30
Italy	
Professor	2
University staff	20
Malaysia	
School teacher	10
Higher education	2
Industry	5
Government	5
Nigeria (1974)	
Physics teachers	3
Poland	
Professor	2
Associate professor	10
Assistant professor	30
School teacher	70
Thailand (1974)	
High school physics teachers	21
U.K. (1974) (see Table A3)	
Physical Society	4
U.K. (1972) (see Table 5)	
National Register	4

Notes

(a) Data from personal contacts in the various countries. Where the name of the country is not followed by a date the information was estimated by conference participants.

Table A6. Mean difference between girls and boys scores on physics attainment tests administered to ten year olds, fourteen year olds and pre-university school-pupils.

	ten year olds	fourteen year olds	pre-university
Western			
Australia	–	58	81
Austria*	–	60	–
Belgium (Flemish)	41	63	72
Belgium (French)	39	46	70
England and Wales	47	43	101
Finland	48	80	119
France	–	–	88
Fed. Rep. of Germany	53	77	88
Italy	38	58	74
Netherlands	56	68	96
New Zealand	–	61	99
Scotland	42	66	110
Sweden	50	63	104
U.S.A.	34	56	62
Asian			
India	1	30	13
Iran	5	–	–
Thailand	40	23	29
South American			
Chile	26	46	43
East Europe			
Czechoslovakia*	–	25	94
German Dem. Rep.	–	45	–
Hungary	37	62	63
Poland*	–	8	–

Notes

(a) Data from Comber and Keeves [8], Tables 6.15, 6.16, 6.17 and Hnilicková [13], Tables I, III.

(b) Data on countries marked * is taken from Hnilicková [13]. The samples for this study were less carefully drawn than those for the IEA study, and the results are therefore less reliable.

(c) The figures are standardized score units:

$$\frac{\text{difference between mean scores of boys and girls} \times 100}{\text{average standard deviation for all countries}}$$

20 The contribution of students to the improvement of physics teaching

Physics teaching is concerned with students. They may have a greater contribution to make to the improvement of physics teaching methods, to curriculum development and to the production of instructional materials than has been appreciated in the past. Some work involving students has been initiated in the United States. This chapter, based on a paper by A.A. Strassenburg, surveys this trend and indicates some of the conclusions to be drawn from it.

20.1 THE USE OF STUDENTS AS TUTORS IN SELF-PACED COURSES

The idea behind the Personalized System of Instruction (PSI) is that students enrolled in a course will study, to some extent at least, *what* topics interest them *when* they are intellectually and psychologically prepared for them. The scheme, as described by Keller [1] calls for the use of advanced students as tutors of less advanced students. No one instructor is to determine when and in what way a student will investigate new ideas. Even though it is clear that students in such a course need to rely heavily on printed matter, laboratory work, audiovisual materials and all manner of independent study methods, Keller did not propose that students should receive no instruction directly from persons more knowledgeable in the subject than they. He did recognise however, that self-paced instruction for a class of typical size and instruction by a single master teacher are not compatible, and therefore the concept of student tutors seemed to him an essential ingredient of the system. When a student is used as a tutor, he or she becomes influential in determining what and how well other students learn. He or she is also in a position of potential influence on decisions concerning the design of course materials, instructional systems and the evaluation of learning.

A large number of trials of variations of the Keller Plan have been conducted, and a significant number of these have been reported in the literature. Surprisingly, few of these reports make any mention of student tutors. In particular, the author studied with care articles on the use of PSI written by Gueths [2], Gilmore [3], Anderson and Artman [4], Austin and Gilbert [5], and Swartz and Zipfel [6]. While each of these papers contains valuable information on trials and modifications of Keller Plan courses, none mentions the use of student tutors. Either student tutors take little part in these systems or the systems functioned without student tutors; the latter conclusion seems quite consistent with the course descriptions in almost all cases.

Reports on PSI course trials that *do* mention student tutors have been published. Green [7], [8] repeatedly refers to student tutors as high quality and willing performers who are essential to the system he employed at Massachusetts Institute of Technology. In neither of these references does he elaborate on the role students played in influencing the content of the course or the design of the instructional system. Nor is there any evidence in either article that an effort was made to evaluate how effectively the students functioned in their role as tutors. Philippas and Sommerfelt [9] present a more quantitative but even less analytical report on the use of student tutors. They operated a large system, therefore their comments carry the weight of statistical significance. In making work assignments, they did not distinguish between the functions of a tutor and a proctor; presumably this means that the students they employed performed as administrators of unit mastery tests and perhaps also evaluators of student performances on mastery tests. If so, this is exactly the kind of responsible student role that deserves careful analysis and assessment. Unfortunately, we learn from this report only that one third of the student tutors were rewarded with course credit and two-thirds were paid.

In a 1974 publication Roper [10] discusses the use of 'bootstrap tutors', that is tutors who are enrolled in the course they are tutoring. He lists three advantages that result from this practice. (1) Bootstrap tutors are easier to recruit than students who have already completed the course. (2) The best students in a course are better able to help less able students with specific course problems than persons who have not recently encountered and solved those problems. (3) Tutoring results in very thorough learning, and this is of more immediate benefit to enrolled students than to anyone else.

A recently published article by Kahn and Strassenburg [11] reports a more novel use of undergraduate students in the instructional process. Some 40 students who had completed a one-year introductory college physics course one or two semesters earlier were enrolled in a course entitled 'Instructional Research'. Part of their weekly duties consisted of providing tutorial assistance to about 400 students currently enrolled in the introductory course. This tutorial activity centred around an open laboratory that also served as a learning centre in the sense that audio-visual materials were available there, course announcements were posted there, and staff members assigned to this course congregated there. Mastery tests, however, were administered elsewhere and undergraduate tutors never served as test proctors.

The other part of the work performed by tutors enrolled in the research course involved these students in the analysis of aspects of the instructional system then used by the director of the introductory course. Each group of four or five tutors, during each of two or three different periods during the semester, were expected to identify components of the introductory course system that functioned poorly, to propose a better method of accomplishing the intended purpose of that component, to implement a pilot model of the proposed improvement and to monitor the success of the innovation. Some interesting attempts were made to improve the system; some were judged by the course director to have such merit that they were subsequently adopted as part of the standard operating procedure. Other projects made no lasting impact on the instructional system but may have provided valuable educational research experiences for the tutors. No quantitative evaluation of the value of the research course is provided in the reference, but the authors assert that the existence of the research course improved the morale of students enrolled in the introductory course.

Self-paced instruction is not confined to tertiary education. In an article entitled 'Physics Without a Teacher' [12] Bolin, Ignatz and Lewis report on Project Physics materials that permit school students to learn physics through self-study. The students who initially tested these materials did have access to a tutor, a senior student, but the tutor was not competent to provide more than general advice on how to conduct a physics experiment. While the students certainly did have control of their own learning, they did not directly contribute to the design of the instructional system. An evaluation of the tests of these materials is discussed in this article.

20.2 DEVELOPMENT OF INSTRUCTIONAL MATERIALS BY STUDENTS

One way to give students input to the teaching-learning process is to involve them directly in the preparation of instructional materials. As far as we know, the only person who has done this with both undergraduates and graduates in order to enrich the physics education of the students is Peter Kahn of the State University of New York at Stony Brook. This work was reported in some detail in reference [11]. The paragraphs below are quoted directly from that article.

> "We identify capable students at three different stages of their education and invite them to participate in the development of curriculum materials: (1) advanced undergraduates who seek graduate careers in the physical sciences, (2) advanced undergraduates or master's degree candidates who seek careers in high school teaching, and (3) graduate students who wish to have a more adequate teaching experience than is afforded them by the traditional teaching assistantship. To accommodate students from all of these backgrounds we concentrated our efforts on the development of curricular materials in modular format. Our modules are independent learning units, covering a limited amount of subject matter. They are suitable as enrichment materials to complement textbooks.
>
> Most modules contain (1) prerequisites and goals, (2) a short narrative section, (3) experiments, (4) problems and tests, (5) bibliography and references for collateral reading, and (6) suggestions for related projects. Each module is a modest undertaking in order to be within the capabilities of the student. The initial work is most frequently done during the summer, and students are given the opportunity to continue and refine their efforts during the school year. Academic credit toward graduation is awarded for the activities pursued during the academic year (through research project courses) and outstanding modules are considered suitable as part of a student's research toward an honours degree in physics. The students are also given the opportunity to present their work at local meetings of the American Association of Physics Teachers.
>
> Module projects fall into four categories. (1) Experiments suitable for use in introductory physics courses. (2) Self-paced materials designed to cover some aspects of physics not usually covered within the physics undergraduate curriculum. (3) Modules which are centred around the design of demonstrations for use in introductory courses. (4) Modules which are concerned entirely with problems outside physics.
>
> As a result of these activities, students have been attracted to the idea of more active participation in the learning process. More important, they have welcomed the opportunity to work, to make apparatus function and to see their ideas used in a college physics course. Finally, they have had the opportunity, traditionally reserved for the faculty, to gain some experience in the design of teaching materials. This neglected part of students' education is particularly useful for those who will go on to teach."

20.3 STUDENT-ORIGINATED RESEARCH

A substantial part of the education of an undergraduate specializing in physics consists of courses and extracurricular experiences that prepare him for the world of research. While many students may well have originated the research ideas which they pursued, we will confine our discussion in this chapter to the formal programme entitled 'Student Originated Studies' (SOS) conducted by the National Science Foundation (NSF) in the U.S.A. Under this programme, a group of students who wish to receive NSF support for their efforts must submit a formal proposal, have it reviewed and prepare reports on the results of their research. Almost all of the projects supported under this programme focus on problems that could be classified as environmental in nature.

Typical problems studied by such groups might involve measurements of a specific pollutant in a particular stream or the use of land in a particular city.

Student groups typically conduct the bulk of their SOS research work during the summer. They are required to name a faculty sponsor, but this person serves primarily as a responsible fiscal agent and an advisor; students do generate the research ideas, prepare the proposal, conduct the research and write final reports themselves. The independence of action and the level of responsibility this requires is probably a more valuable acquisition for the student participants than any specific information the students may acquire.

Guyford Stever, Director of NSF, in his foreword to the 1971 report of SOS projects [12] commented on the benefits of participation identified by students as follows:

> "Student participants repeatedly have pointed to how much they have gained from having to (1) focus upon meaningful topics and practical designs; (2) organise teams so as to achieve needed balance in expertise and recruit suitable project advisors to reinforce the effort; (3) forge functioning teams out of individuals with highly diverse backgrounds and then continuously subjugate personal differences so as to maintain the strong sense of mission required to keep the work moving steadily toward its goals; (4) establish productive relationships with industrial, governmental, and other public bodies; (5) interface effectively with their funding agency and with officials of the host institutions; (6) monitor progress and reassess goals on a continuing basis, making midcourse adjustments as results define the most productive avenues of inquiry; and (7) keep diligently at the task of translating the findings into usable reports, for the benefit of all who are concerned about good environmental management and good education."

An evaluation of the programme [13] was conducted by Stephen M. Smith and Joseph G. Coleman in 1974. The goals of the evaluation were (1) to identify the effect of the SOS programme on all involved persons and institutions; (2) to determine those SOS projects that have influenced institutional, participant, and community change; and (3) to determine those variables that differentiate influential projects from less influential projects. The findings of the study are summarized below.

SOS does result in increased emphasis on independent study in the regular curriculum and the introduction by the faculty of new materials or instructional techniques. The NSF places top priority on the former and lower priority on the latter, while in practice the actual outcome strongly favoured the latter activity.

To some extent, science departments holding SOS grants did develop and teach courses on environmental and social problems and they did initiate student-designed courses. Again, however, the relative extent to which these goals were realised is reversed from the ranking of importance of the activity among NSF programme officers.

Only one-fifth of the institutions that conducted SOS programmes increased the number of environmental courses as a result of their involvement in the SOS programme.

With regard to participants, the research findings disclose that (1) participants did to a high degree increase their research skills, knowledge of their disciplines and interdisciplinary teamwork ability; (2) participants increased their perceived administrative and organizational skills; (3) over half the participants and two-thirds of the Project Directors felt that SOS enabled them to contribute to the solution of social and environmental problems; (4) the same fractions felt they could now carry out a research project of their own; (5) three-quarters of the participants were persuaded of the need for interdisciplinary science research; (6) participants did *not* develop more favourable attitudes toward independent study as a result of their SOS experiences.

Finally SOS projects seem to have had considerable influence on the way local communities make decisions concerning environmental issues.

Guyford Stever summarized many of the valuable characteristics of the programme in the foreword to the 1973 NSF Report of SOS Projects [14]. He refers to the value of coming to grips with genuinely difficult and challenging problems, including local problems of social importance. He describes how interdisciplinary teams of students are demonstrating that objectives and structures that initially appear to be mutually exclusive can often be reconciled. Readable summaries of the SOS programme are contained in references [15] and [16]. More detailed descriptions of individual student projects are contained in references [12], [14] and [17]. In addition, there is an interesting article by Weinberg [18] describing his method for providing research opportunities for undergraduates on a modest scale.

Except for the NSF SOS programme, opportunities for students to influence the structure and content of their own educational programmes have been regrettably few. This is an area that deserves more attention from physics teachers in the future.

20.4 BIBLIOGRAPHY

1. Keller, F.S. *'Goodbye Teacher'*, J.Appl. Behavior Anal. *1*, 78 (1968).
2. Gueths, J.E. *'A Learning and Student Self-Evaluation'.* J. Coll. Sci Teach., *2*, 30 (February 1973).
3. Gilmore, J.B. *'Learning and Student Self-Evaluation'*, J. Coll. Sci. Teach, 3, 54 (October 1973).
4. Anderson, O.T. and Artman, R.A. *'A Self-paced, Independent Study, Introductory Physics Sequence-Description and Evaluation'*, Am. J. Phys. *40*, 1737 (1972).
5. Austin, S.M. and Gilbert, K.E. *'Student Performances in a Keller Plan Course in Introductory E. & M.'* Am. J. Phys. *41*, 12 (1973).
6. Swartz, C.E. and Zipfel, C. *'Individualised Instruction in Introductory Physics'.* Am. J. Phys. *40*, 1436 (1972).
7. Green, Ben A. Jr. *'Is the Keller Plan Catching on Too Fast?'* J. Coll. Sci. Teach. *1*, 50 (October 1971).
8. Green, Ben A. Jr. *'Physics Teaching by the Keller Plan at MIT'* . Am. J. Phys. *39*, 764 (1971).
9. Philippas, M.A. and Sommerfeldt, R,W. *'Keller vs. Lecture Method in General Physics Instruction'.* Am. J. Phys. *40*, 1300 (1972).
10. Roper, David L. *'Personalised Instruction with Bootstrap Tutors in an Introductory Biophysics Course'.* Am. J. Phys. *42*, 27 (1974).
11. Kahn, P.B. and Strassenburg, A.A. *'Instructional Innovations in Physics at Stony Brook'.* Am. J. Phys. *43*, 400 (1975).
12. Bolin, C.M., Ignatz, M., and Lewis, R. *'Physics without a Teacher – A Model for Independent Study of the Project Physics Course'.* The Phys. Teach. *11*, 469 (1973).
13. Smith, S.M. and Colmen, J.G. *'Analysis of the Impact of the National Science Foundation Programme of Student-Originated Studies'*, unpublished.
14. Hill, B.F. (ed). *Student-Originated Studies Projects, 1973 – Abstract Reports*, National Science Foundation, Washington, D.C. 20550.
15. Young, L.J. and Purcupile, J.C. *'Student Originated Studies'.* J. Coll. Sci. Teach. *2*, 15 (December 1972).
16. Barton, A.J. *'Student-Originated Studies Program'.* J. Coll. Sci. Teach. *3*, 14 (October 1973).
17. Hill, B.F. (ed). *Student-Originated Studies Projects, 1972 – Abstract Reports*, National Science Foundation, Washington, D.C. 20550.
18. Weinberg, Robert. *'Introducing Undergraduates to a Research Laboratory'.* The Phys. Teach. *12*, 263, (May 1974).

Appendix I

THE INTERNATIONAL CONFERENCE ON PHYSICS EDUCATION: EDINBURGH 1975

This account of the Edinburgh Conference is partly based on the article by Lester G. Paldy, which appeared in the November 1975 issue of the journal The Physics Teacher, and partly on the article by W.F. Archenhold, published in the January 1976 issue of Physics Education. Grateful acknowledgement is made to these two authors and to the two journals for permission to use their articles in this way.

About 330 people actively involved in physics education, coming from nearly 80 countries, gathered in Edinburgh (United Kingdom) from 29 July to 6 August, 1975, to participate in the International Conference on Physics Education convened by the International Union of Pure and Applied Physics (IUPAP) through its International Commission on Physics Education (ICPE). The Conference was also sponsored and supported by Unesco, the Royal Society, the Institute of Physics and the University of Edinburgh. Further financial support was provided by the British Council and a number of official and private organizations in the United Kingdom.

ICPE is one of the 16 commissions of the International Union of Pure and Applied Physics (IUPAP) which, in turn, is one of the 17 scientific unions of the International Council of Scientific Unions (ICSU). ICPE was under the chairmanship of Dr W.C. Kelly at the time of the conference. Since September 1975, the Commission has been chaired by Professor A.P. French (Department of Physics, Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.) with John L. Lewis (Malvern College, Malvern, Worcestershire, U.K.) as Secretary.

Organizing international conferences of special interest to those concerned with physics education has been a major activity of ICPE since it was founded in 1960. The first international conference on physics education was held at Unesco in Paris in 1960 [1]. This Paris conference in fact preceded the foundation of ICPE and was largely responsible for its establishment under its first Chairman, Professor Sanborn C. Brown. This first conference, which covered fairly broadly the whole area of physics education, was followed by a series of others on specific topics: on physics in general education, held in Rio de Janeiro, Brazil, July 1963 [2]; on the education of professional physicists, London, U.K., 1965 [3] on the education of physicists for work in industry, Eindhoven, Netherlands, 1968 [4]; on the education of teachers of physics for secondary schools, Eger, Hungary, 1970 [5]; on the role of the history of physics in physics education, Cambridge, U.S.A., 1970 [6].

There have been many interesting developments in all aspects of physics education since the first general international conference held in 1960. ICPE felt, therefore, that the time had come for another international conference covering the whole field of physics education, to assess what had been achieved and to identify what needed to be done in the future. This coincided with Unesco's plans to support such a conference and to collaborate with ICPE on the planning of it. Preliminary discussions were initiated in 1973, leading eventually to the holding of the Edinburgh Conference in 1975.

This Conference had the following aims: (1) to identify and analyze recent trends and present problems in physics education with particular reference to schools and universities; (2) to prepare guidelines for the improvement of physics education which could assist national and local instutions as well as international and regional organizations; (3) to produce materials, based upon the discussions of the working groups, for publication in volume III of the Unesco series “New Trends in Physics Teaching”.

The work of planning and organizing the Conference was shared among three committees: an international planning committee (under the chairmanship of Professor A.P. French) which included physics educators from all parts of the world; a national committee (under the chairmanship of Professor C.A. Taylor); and a local organizing committee (under the chairmanship of Professor W. Cochran). The international planning committee selected 20 topics for consideration at the Conference and subsequently invited 20 authors to prepare a working paper, each paper giving an outline of present trends and problems in one of the selected topics as well as suggestions for action. These papers formed the basis for discussions in working groups at the Conference. As part of the preliminary steps in the planning of the Conference, a world-wide Survey of literature on physics education was commissioned by Unesco. This Survey was made available to the authors of the 20 "trend papers", and subsequently also to the Conference participants who wished to purchase a copy of it.

The old city of Edinburgh provides a working environment that would be very hard to surpass. The basic organizational details of the Conference were attended to by a dedicated local organizing committee chaired by Professor W. Cochran, with R.M. Sillitto as Secretary and Dr P.J. Kennedy as Treasurer, supported by other persons too numerous to mention here. The entire programme went very smoothly.

The only feature which did not live up to expectations was the weather! The brochure advertising the Conference warned that "visitors to Scotland are generally surprised by the briskness of the Scottish summer. The daytime temperature in Edinburgh seldom rises above 18°C in early August, and it is usually advisable to carry some protection against rain". In the event, the visitors as well as the locals were pleasantly surprised by the spendid weather which the U.K. enjoyed during July and August 1975. The temperature seldom fell below 18°C and the only protection required was against the sun! The warm sunshine obviously also helped the 150 or so accompanying members in their enjoyment of the excellence of the local arrangements made on their behalf.

Much of the work of the Conference was done in 20 working groups, covering each of the topics that had been selected by the international planning committee. Every Conference participant was a member of two of these groups. Discussions were broadly based on the above-mentioned 'trend papers', which had been prepared and circulated in advance of the Conference. Each group met on three occasions (for three hours each time) and at the end of each session the Chairman and Secretary, in consultation with the author of the trend paper, produced a short report which was published, with other news items, in the daily 'bulletin'. This enabled participants to get some idea of the progress made in working groups of which they were not members, and, if they so wished, to pass comments to the Chairman or to other participants of such groups. Appendix II gives the name of the author of the trend paper for each of the 20 topics and the names of the Chairman and Secretary of the corresponding working groups.

The second major feature of the Conference was the series of plenary sessions. Simultaneous translation facilities were provided from English to French and French to English. The main speakers were: Sir Hermann Bondi (UK) on 'Physics, education and society' [7]; Pierre Aigrain (France) on 'Where is physics going?' [8]; A.R. Kaddoura (Syria) on 'Where is education going?' [9]; H.B.G. Casimir (Netherlands) on 'Education, physics and technology' [10]; V.F. Weisskopf (U.S.A.) on 'Is physics human?' [11]; Kevin Keohane (U.K .), Rais Ahmed (India), Joseph Elstgeest (Lesotho) and E.W. Hamburger (Brazil) who contributed to the plenary session on 'New science and old cultures' [12]; and Eric Rogers (U.K.) who gave a lecture-demonstration on the theme 'Let young people enjoy their physics and gain intellectual satisfaction from its study' [13].

One of the highlights of the Conference was the interesting display of materials from a great variety of recent and current physics education projects from many countries. This was organized by E.J. Wenham (Worcester College of Education, Worcester, U.K.), who invited physics curriculum groups from all over the world to send or to bring exhibits to the Conference. The display in Edinburgh included one exhibit from each of the following countries: Denmark, France, Federal Republic of Germany, Kenya, Philippines, Trinidad and Venezuela; two exhibits from Brazil and from Italy; three from the U.S.A.; and eleven from the U.K. (An annotated list of these exhibits is given in Appendix III, with addresses from which further details on each project can be obtained.) There was much interest in these exhibits among the Conference participants, judging by the number who came to visit them and by the lively discussion groups that often formed around them.

The Conference included an exhibition of physics teaching apparatus, which was organized by Geoffrey Foxcroft (Rugby School, U.K.). It included a number of exhibits provided by British universities and an exhibit brought by an Italian team headed by Professor Loria. Most of the exhibits, however, came from commercial manufacturers of physics teaching apparatus: one from France, two from the Federal Republic of Germany, one from India, one from Italy, one from the United States and twelve from the United Kingdom. The apparatus exhibited covered a wide range – from elementary kits to the more complex and sophisticated apparatus as well as analog and digital computer units.

Another useful feature of the Conference was the large exhibition of physics texts and other science teaching publications. Many participants were struck by the attractiveness of the books and their suitability for a variety of purposes. The exhibit was arranged by G.R. Noakes.

A particularly interesting feature of the Conference was the showing of films useful in physics teaching or in the training of teachers. The film sessions were organized by Miss B.M. Jennison (Department of Education, Cambridge University U.K.). Maximum use was made of the limited time available (two evening sessions) by showing well selected extracts from a large number of films from all over the world, instead of showing fewer films in their entirety. In this way it became possible to illustrate and to discuss different ways of using films in physics teaching. Facilities were also available for members of the Conference, on a self-service basis, to see complete films at other times or to show their own films to other participants.

Each evening (except for the two that were devoted to film sessions) featured a social event. One of them, in association with the Royal Society of Edinburgh, was a tribute to Professor Norman Feather, the distinguished nuclear physicist, on the occasion of his retirement from the chair of Natural Philosophy at the University of Edinburgh. His evening discourse entitled 'Twice thirty years of physics' was much appreciated.

The various social functions all had a Scottish flavour, characterized by the lone piper walking on the balcony of the Royal Scottish Museum at the reception given by H.M. Government. Other receptions were offered to participants by the City of Edinburgh, the University of Edinburgh and by the British Council. In short, the Conference organizers succeeded in their efforts to provide an environment in which the participants could enjoy their hard work at the Conference.

REFERENCES

1. The proceedings of the Paris Conference are published in *International Education in Physics,* ed. Sanborn C. Brown and Norman Clarke, M.I.T. Press, 1960.
2. The proceedings of the Rio de Janeiro Conference are published in *Why Teach Physics?*, ed. Sanborn C. Brown, Norman Clarke, Jayme Tiomno, M.I.T. Press, 1964.
3. The proceedings of the London Conference are published in *The Education of a Physicist,* ed. Sanborn C. Brown and Norman Clarke. Oliver and Boyd, 1966.
4. The proceedings of the Eindhoven seminar are published in *The Education of Physicists for Work in Industry,* ed. G. Diemer and J.H. Emck: Centre Publishing Company, Eindhoven, 1969.
5. The proceedings of the Eger Conference are published in *Teaching Physics – An Insoluble Task?* ed. Sanborn C. Brown, F.J. Kedves, E.J. Wenham. M.I.T. Press, 1971.
6. The proceedings of the M.I.T. seminar are published in *History in the Teaching of Physics,* ed. Stephen G. Brush and Allen L. King. University Press of New England, 1972. Also published as an outcome of the seminar: *Resources for the History of Physics,* ed. Stephen G. Brush. University of New England Press, 1972.
7. Sir Hermann Bondi's lecture is published in *Physics Education,* Vol. 10, No. 7, November 1975, p. 469–474.
8. Professor Aigrain's lecture is published in *Physics Education,* Vol. 10, No. 7, November 1975, p. 475–480.
9. Professor Kaddoura's lecture is published in *Physics Education,* Vol. 10, No. 7, November 1975, p. 481–486.
10. Professor Casimir's lecture is published in *Physics Education,* Vol. 11, No. 1, January 1976, p. 11–15.
11. Professor Weisskopf's lecture is published in *Physics Education,* Vol. 11, No. 2, March 1976.
12. The four talks on New Science and Old Cultures are published in *Physics Education,* Vol. 11, No. 1, January 1976, p. 16–27.
13. Professor Rogers' lecture is published in *Physics Education,* Vol. 11, No. 5, July 1976.

Appendix II

THE WORKING GROUPS AT THE EDINBURGH CONFERENCE

Listed below are the Working Groups at the Conference together with the names and addresses of the authors responsible for the 'trend papers', which formed the basis for the discussions, and the Chairman and Secretaries of each working group.

1. *The Postgraduate Education of Physicists.*
   Martin Cernohorsky, Purkyne University, Faculty of Natural Sciences, Kotlarska 2, 611 37 Brno, Czechoslovakia.
   Chairman: E.L. Jossem Secretary: J. Oitmaa
2. *Physics Curricula and Courses for Physics Undergraduates.*
   P.J. Black, Dept. of Physics, University of Birmingham, Box 363, Birmingham, U.K.
   Chairman: D. Ivey Secretary: N. C. Barford
3. *New Approaches to Teaching and Learning in Universities.*
   M.A. Moreira, Instituto de Fisica, UFRGS, 90000 Porto Alegre, R.S. Brazil.
   Chairman: D. Fincham Secretary: W.R. Hogg
4. *The Role of the Laboratory in Physics Education.*
   J.A. Eades, Physics Dept., University of Bristol, U.K.
   Chairmen: M. Palma-Vittorelli, E.J. Burge Secretary: C. Crellin
5. *From School to Higher Education.*
   J.M. Ogborn, Centre for Science Education, Chelsea College, Bridges Place, London, U.K.
   Chairman: D. Sette Secretary: H. Bunton
6. *Educational Technology in the Teaching and Learning of Physics.*
   A.V. Baez, Lawrence Hall of Science, University of California, Berkeley, California 94720 U.S.A.
   Chairman: B. McInnes Secretary: R.A. Sutton
7. *New Approaches to Teaching and Learning in Schools.*
   E.J. Wenham, Worcester College of Education, Henwick Grove, Worcester, U.K.
   Chairman: A. Loria Secretary: M.J. Harrap
8. *The Effect on Physics Education of a Better Understanding of the Psychological Process of Learning.*
   L. Leboutet, Université de Paris VII, Tour 23 5^{e} étage, 2 place Jussieu, 75221 Paris, France.
   Chairman: J. Elstgeest Secretary: G. Strumane
9. *The Process of Course and Curriculum Development.*
   A.A. Strassenburg, Division of Science Education Development and Research, National Science Foundation, Washington, DC 20550, U.S.A.
   Chairmen: F.R. Stannard, P.B. Kahn, R. Ahmed Secretaries: E. Taylor, J.G. Jones
10. *Diffusion of Innovations in Physics Education into National Systems.*
    J. Reay, School of Education, University of West Indies, Saint Augustine, Trinidad, British West Indies.
    Chairman: H. Meiners Secretary: H.A. Daw
11. *The Interface between Physics and Mathematics.*
    K. Maurin, Dept. of Physics, University of Warsaw, Poland (University level) and W.U. Walton, Educational Development Centre, 55 Chapel Street, Newton, Massachusetts 02160, U.S.A. (School level).
    Chairmen: J. Werle, E. Nagy Secretaries: M.G. Ebison, G.R. Noakes

12. *The Assessment of Student Achievement.*
C.B. Oguntonade, Continuing Education Centre, University of Lagos, P.O. Box 56, Akoka Lagos, Nigeria.
Chairman: E.J. Burge Secretary: R.J. Osborne

13. *Integrated and Multi-disciplinary Curricula at the Secondary Level.*
G. Delacôte, Université de Paris VII, Tour 23 5^{e} étage, 2 place Jussieu, 75221 Paris, France.
Chairman: E. Baurmann Secretary: D. Reid

14. *Pre-service and In-service Training of Secondary School Physics Teachers.*
M. Ferretti, Via Luca Ghini 6, 40136 Bologna, Italy.
Chairman: P. Thomsen Secretary: D.A. Tawney

15. *Physics for Technical Education and Technological Literacy.*
N.H. Frank, Dept. of Physics, Massachusetts Institute of Technology, Cambridge, Mass. 02139, U.S.A.
Chairman: N.H. Frank Secretary: A.G. Campbell

16. *Physics and Recent Trends in Education.*
E.W. Hamburger, Instituto de Fisica, Universidade de Sao Paulo, Cidade Universitaria, Caixas Postais 20516, 8219 Sao Paulo, Brazil.
Chairman: M.M. Hurst Secretary: D. Carter

17. *Science and Society; Scientific and Technological Aspects of Current Problems of Society.*
J.M. Fowler, Dept. of Physics, University of Maryland, College Park, Maryland 20742, U.S.A.
Chairman: B. Robinson Secretary: L. Cohen

18. *Out-of-School Science Acitivities.*
F.L. Wattier, I.C.C., rue de Veeweyde 125, B-1070 Brussels, Belgium.
Group worked with No. 16.

19. *Women in Physics and Physics Education.*
A. Kelly, Centre for Educational Sociology, University of Edinburgh, 24 Buccleuch Place, Edinburgh, U.K.
Chairman: V. Kistiakowsky Secretary: A. Kelly

20. *The Contribution of Students to the Improvement of Physics Education.*
A.A. Strassenburg, National Science Foundation, Washington DC 20550, U.S.A.
Group worked with No. 9.

Appendix III

PHYSICS CURRICULUM PROJECTS EXHIBITED AT THE EDINBURGH CONFERENCE

This list is based on that prepared by John M. Fowler and published in the November 1975 issue of the journal 'The Physics Teacher'. Grateful acknowledgement is made to the author and to the journal for permission to reproduce it. Further details can be obtained from the addresses given for each project.

Ask Nature, Denmark. A curriculum and materials development programme for Danish schools producing physics textbooks which integrate experimentation and theory. The first material is for students of about age 14. Professor Poul Thomsen and Dr E. Flensted-Jensen, Royal Danish School of Education Studies, Emdrupvej 115B, Copenhagen IV, Denmark.

Computers in the Curriculum, U.K. This programme is producing simulation programmes in BASIC, which, when put in place on a computer, allow students to plan and carry out experiments, i.e., to set parameters and initial conditions and obtain results. For advanced secondary school students or first year university students. Dr R. Lewis, Centre for Science Education, Chelsea College, Bridges Place, London SW6 4HR, U.K.

East African Secondary Science Project (Kenya, Tanzania, Uganda). Modelled after the English Nuffield programme, but independently developed and adapted for the East African system. For advanced high school students. Dr D.J. Sloan, Kenya Institute of Education, P.O. Box 30231, Nairobi, Kenya.

Estudios Libres (Free Studies), Venezuela. "Education at a distance". It uses television programmes and printed materials to upgrade Venezuela physics teachers. Professor Biagio Murgia, Universidad Simon Bolivar, Apartado 5354, Caracas, Venezuela.

Funbec, Brazil. This Brazilian foundation develops and produces inexpensive science education materials – kits and books – which are sold on the market directly, instead of through schools. Dr A.S. Teixeira, Caixa Postal 2089, Sao Paulo, S.P., Brazil.

Higher Education Learning Project (Physics), U.K. A tutorial project in which small groups of students work as a team in problem solution. For university level physics students. J.M. Ogborn, Centre for Science Education, Chelsea College, Bridges Place, London SW6 4HR, U.K.

Independent Learning in Science, U.K. A cooperative effort of a group of teachers to produce a learning packet (work sheets, etc.) to help science students in English secondary schools. An attempt to better the match between mixed ability students and the various science programmes. E.L. Green, Countersthorpe College, Winchester Road, Leicester, LE8 3PR, U.K.

Initiation aux Sciences et Techniques, France. A group of physicists and teachers is engaged in the production of modules on such topics as automation, photography, and polymers, to be used in secondary education. Initiation aux Sciences et Techniques, University of Paris VII, 2 place Jussieu, 75221 Paris, France.

Iniziativa Relativita, Italy. The introduction of special relativity as a physics topic in Italian secondary schools. The project members are undertaking educational research on teaching and learning in physics at this level. Professor G. Cortini, Instituto di Fisica "G" Marconi, Universita degli Studi, Roma, Italy.

Institut fur die Padagogik der Naturwissenschaften, Germany. A curriculum development project on physics for students in the last two years of secondary school. It emphasizes the use of processes and equipment already available in the student's environment. It combines theory and experiment. Dr P. Haussler, I.P.N., an der Universitat Kiel, Olshausenstrasse 40–60, D2300 Kiel 1, Federal Republic of Germany.

Mathematics and Science Centre, Dundee, Scotland. The Scottish Centre for Mathematics, Science, and Technical Education has several curriculum projects. Most of the activity so far has been in mathematics, but high school units in biology and general science are also under development.

Nuffield Physics Project, U.K. The Nuffield O-level project is a British curriculum project which has already been extensively reported. E.J. Wenham, Worcester College of Education, Worcester, U.K.; John L. Lewis, Malvern College, Worcestershire, U.K.

Nuffield Advanced Physics Project, U.K. This impressive British A-level project has already been widely reported. Professor P.J. Black, Dept. of Physics, University of Birmingham, Box 363, Birmingham, U.K.; J.M. Ogborn, Chelsea College, Centre for Science Education, Bridges Place, London SW6 4HR, U.K.

Open University, U.K. A massive programme for out-of-school education using television presentation of lectures with correspondence school type lessons supplemented by regional learning centres. The Open University, Walton Hall, Milton Keynes, U.K.

Pennsylvania Nuclear Science Program. A student and a teacher workbook on "The Environmental Impact of Electric Power Generation" with useful source materials for teachers. Pennsylvania Dept. of Education, Harrisburg, PA 17126, U.S.A.

Physics Interface Project, U.K. A cooperative project involving several British Universities and aimed at beginning college students of physics. It is focused on the development of diagnostic procedures, on self teaching units, and on the testing and evaluation of these materials. R.A. Sutton, Dept. of Physics, University College, P.O. Box 78, Cardiff, Wales, U.K.

Physics of Technology Project, U.S. Modular materials primarily for two-year colleges. The materials are based on technical devices such as the analytical balance, the automobile ignition system, binoculars, the camera, the cathode ray tube and the pressure cooker. The physics behind the technology is brought to the surface for study. John McWane and Bill Aldridge, TERC, 575 Technology Square, Cambridge, MA 02139, USA.

Physics Project, Science Education Center, University of the Philippines. Designs and tests programmes for use in high schools. The present physics course was created for Philippine teachers. University of the Philippines, Science Education Center, Diliman, Quezon City, Philippines.

Physics Teaching Project (PEF), Brazil. A curriculum development project for Brazilian secondary schools. It is intended to be a terminal physics course covering mechanics and electricity. Experimentation and theory are integrated. Professor Ernst Hamburger, Instituto de Fisica, Universidad de Sao Paulo, Caixa Postal 20516, Sao Paulo, Brazil.

Project Physics, U.S.A. This well known project has already been extensively reported. Professor J. Rutherford, School of Education, 23 Press Buildings, Washington Square, New York, NY 10003, USA.

School Technology Programme, England. Materials (kits and text) to supplement secondary school physics programmes. The emphasis is on current applications of physics in industry. Dr G. Sneed, c/o The Science Museum, London, U.K.

Science in a Social Context Project, U.K. A cooperative project of several British universities introducing social, historical and philosophical issues into the teacher training programmes of physical science teachers. Dr W.F. Williams, Room 9183, Physics Administration Building, University of Leeds, Leeds, U.K.

Science Teacher Education Project, U.K. A cooperative effort between physics faculties at several British colleges and universities. Activities for use in preservice and inservice training programmes are designed and tested. Dr C.R. Sutton, School of Education, University of Leicester, 21 University Road, Leicester, U.K.

Scottish Schools Science Equipment Research Centre. This centre exists to advise Scottish teachers on all matters affecting science apparatus. They issue apparatus lists for the various Scottish syllabuses, also a regular bulletin on apparatus, and hold equipment exhibitions throughout Scotland. They make a speciality of developing do-it-yourself apparatus. J.R. Stewart, SSERC, 103 Broughton Street, Edinburgh EH1 3RZ, Scotland, U.K.

The Structure of Matter, an Activity-based Science Course, Italy. A course for 14 year old students which develops ideas about the structure of matter in both biological and physical systems. Professor M.B. Palma Vittorelli, Instituto di Fisica dell Universita, Via Archirafi 36, 90123 Palermo, Italy.

West Indian Science Curriculum Innovation Project. An integrated (physics, chemistry, biology and earth sciences) secondary school programme developed locally and used extensively throughout the English speaking Caribbean Islands. Judy Reay, University of Trinidad, Trinidad.

Appendix IV

LIST OF PARTICIPANTS IN THE EDINBURGH CONFERENCE

Dr T Adolfsson	Sweden
Prof J Agabra	France
Prof M S Ahmed	Egypt
Prof R Ahmed	India
Prof P Aigrain	France
Dr G J Aitchinson	Australia
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Mr W F Archenhold	United Kingdom
Dr P Aspden	United Kingdom
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Dr A V Baez	United States of America
Prof M S Baghdadi	Unesco/Morocco
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Prof M R Bhiday	India
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Fr M Drohan	Kenya
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Mr M J Elwell	United Kingdom
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